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ABSTRACT

This study describes the relationship of two cognitive variables, logical thinking and disembedding ability, to learners' abilities to make conceptual shifts from less acceptable to more acceptable conceptual understandings of a physical phenomenon. The difference in the logical thinking and disembedding ability of students who exhibited different levels of conceptual understanding of an event ranged from no understanding to an acceptable level of understanding. The differences in the logical thinking and disembedding ability of students who were able to make a conceptual shift were compared to those who did not make a shift. Recommendations for curriculum, teachers, logical thinking skills, learners, and for further research are included. Student worksheets, Test of Logical Thinking (TOLT), Group Embedded Figures Test (GEFT), an explanation of the burning candle event, a conceptual understanding form, and a student permission form, are appended. (KR)

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THE RELATIONSHIP OF LOGICAL THINKING AND DISEMBEDDING ABILITY TO A CONCEPTUAL SHIFT USING A PHYSICAL SCIENCE CONCEPT

DISSERTATION

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of the Ohio State University

by

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***

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CHAPTER I

INTRODUCTION

NEED FOR THE STUDY

> "Human beings are theory builders; from the beginning we construct explanatory structures that help us find the deeper reality underlying surface chaos." (Carey, 1985)

Wittrock (1974; 1978) describes learning as a generative process, one in which learners are constantly interacting with the elements in their environment to order to comprehend their surroundings. Wittrock maintains that a learner must actively construct meaning in order to learn with understanding. Learning is a process by which memories, knowledge, and experience are acted upon by the learner to construct a meaningful explanation of the world.

Science can be described as one of the processes by which people can investigate their natural surroundings and construct a body of knowledge that explains how the natural world works. It appears that children come to school with a well-developed body of knowledge of how the world works. This body of knowledge, called "children's science," has been

documented by many researchers (Carey, 1985; Clough & Driver, 1985; Erickson, 1979; Nussbaum & Novak, 1976). Childrens' version of science has the following characteristics: (1) Children hold many ideas about science concepts; (2) Childrens' views differ from scientists' views; (3) Childrens' views are difficult to change. These views sometimes regress before they become more congruent with accepted views (Osborne & Wittrock, 1983).

Children construct a conceptual understanding of the world by interacting with their environment almost from the moment of birth. Childrens' science is affected by their interactions with their peers, their parents and with environmental factors such as television, museums, books, magazines, and newspapers. Other variables, including gender, cognitive style, IQ, and level of logical thinking may also affect childrens' construction of knowledge (Fisher & Lipson, 1986).

When children enter school and are exposed to formal education, they are presented with new ideas, some of which may or may not clash with their conceptual structure of how the world works. Posner, Strike, Hewson & Gertzog (1982) describe the situation that occurs when a child encounters a new idea that is

congruent with what that child already knows. This congruent idea is assimilated into his conceptual structure. This process is called "assimilation." If the child has constructed an explanation of the concept being taught that is not congruent with the accepted scientific explanations he must change or "conceptually shift" his conceptual structure through a process known as " accommodation." Posner et al. (1982) describe four conditions which must be met for accommodation or conceptual shift to occur. First, there must be dissatisfaction with the existing idea. The child's existing explanation must not work for some new situation. Second, the new concept must be intelligible. The symbols and terms used to explain the new concept must be understood by the student. Third, the new concept must be initially plausible. The new concept must fit into the child's existing framework of knowledge. It must be consistent with some past experiences or it must solve some new problem. The fourth and last condition which must be met is that the new concept must be fruitful. Children must be able to use the new concept to explain and to predict events they come into contact with. We know that students do not make conceptual shifts easily (Burbules & Linn, 1988; Gunstone & White, 1981; Linn, 1983; Linn and

Pulos, 1983). Not all students make conceptual shifts, even when teaching methods strive to meet all the conditions listed above.

There is evidence (Claxton, 1987) that children maintain several frameworks of science concepts at the same time. They use "gut science," which they construct from their firsthand experience with the physical world. They construct a "lay science" based on their interactions with peers and experiences with books, television, movies, and museums. In addition to these two forms of science, they are exposed to "school science." School science involves symbolic learning and logical thinking skills. The child is supposed to build a new framework of science concepts which will help him explain the world around him. Some even maintain two separate systems, using " school science" for their teacher and "gut science" and "lay science" for their lives outside of the classroom (Claxton, 1987; Scott, 1987; Williams, Hollan & Stevens, 1983).

Numerous studies have called for a new look at methods for teaching science that will make learning meaningful to students. In light of what we know about "childrens' science," "gut science," and "school science," we know that students come to the science classroom with explanations for why things happen that

may or may not be accurate. There are several sources of these inaccuracies. Children construct concepts and conceptual frameworks from an early age (Carey, 1985). These intuitive conceptions arise first from the child's direct experiences with the world around him and later with the informal educational experiences provided by parents, peers, various informational media such as television and books and by institutions such as museums and zoos. Children use information they obtain from these sources and form concepts and conceptual frameworks which make sense to them.

Another source of misconceptions occurs during formal science learning in school. If formal science instruction does not make sense to the child but does cause some dissatisfaction with previously held concepts, the child may extract from the instruction the bits and pieces that do seem to make sense, and proceed to construct an inaccurate conceptual model which integrates the new information into his/her old framework. We have discovered that many learners do not discard these erroneous explanations even in the face of twelve or more years of science instruction. We also know that a delicate balance exists regarding when to teach what. If we teach concepts too early, students may not understand them, but if we wait too

long, students may have already constructed their own erroneous explanations or "misconceptions" that become more ingrained and with time become harder and harder to dislodge. Before we can make some decisions on the best way to effect a conceptual shift we need to look at the phenomenon of a conceptual shift itself.

Given the growing body of research documenting the misconceptions that children possess and the difficulty learners have in changing their misconceptions, there is a need to study the cognitive variables that come into play when learners make conceptual shifts. If we can describe the characteristics of conceptual shifts and the mechanisms involved in the process we will be in a better position to develop strategies for helping students make these shifts.

PROBLEM STATEMENT

The purpose of this study is to describe the relationship of two cognitive variables, logical thinking and disembedding ability, to learners' abilities to make conceptual shifts from less acceptable to more acceptable conceptual understandings of a physical phenomenon.

The following questions will be examined: (1) Is there a difference in the logical thinking and disembedding ability of students who exhibit different levels of conceptual understanding of an event ranging from no understanding to an acceptable level of understanding? (2) Is there a difference in the logical thinking and disembedding ability of students who are able to make a conceptual shift compared to those who do not make a shift?

RESEARCH HYPOTHESES

I. There will be no significant correlation between the level of logical thinking as measured by the Test of Logical Thinking (TOLT) and the level of conceptual understanding measured on the:

a. pretest
b. posttest
c. follow-up test.

II. There will be no significant correlation between disembedding ability as measured by the Group Embedded Figures Test (GEFT) and the level of conceptual understanding measured on the:

a. pretest,
b. posttest
c. follow-up test.

III. There will be no significant difference in the mean score on the TOLT for the group of students who make a conceptual shift compared to the mean score of the group of students who do not make a conceptual shift at the following times:

a. pretest to posttest (Shift A)
b. posttest to follow-up test (Shift B)
c. pretest to follow-up test (Shift C)

IV. There will be no significant difference in the mean score on the GEFT for the group of students who make a conceptual shift compared to the mean score of the group of students who do not make a conceptual shift at the following times:

a. pretest to posttest (Shift A)
b. posttest to follow-up test (Shift B)
c. pretest to follow-up test (Shift C)

DISCUSSION OF TERMS

Accommodation - the process of rejecting an established concept and its replacement in a conceptual structure. It may be referred to as a conceptual shift (Posner et al., 1982).

Assimilation - the process of incorporating concepts into already existing relevant conceptual structures. This is sometimes referred to as concept elaboration (Posner et al., 1982).

Children's Science - is sometimes referred to as naive science. It is derived from first hand experience and interaction with peers and adults on an informal basis. It usually consists of an independent small conceptual understandings of how the world works (Gilbert, Watts & Osborne, 1985).

Conceptual Shift - occurs when new relations between concepts are represented and new schemata come into being which allow the solution of new problems and change the solution to old problems. Sometimes the core concepts themselves change (Carey, 1985; Champagne, Gunstone & Klopfer, 1985).

Conceptual Understanding - Four levels of conceptual understanding have been defined.

1. no understanding - no explanation is given.

2. naive understanding is an explanation that is not in agreement with the standard explanation.

3. partial understanding is one that is in agreement with the standard explanation but some of the key points are missing.

4. adequate understanding is one that is in agreement with the standard explanation of the concept.

Disembedding Ability - a cognitive style tendency which describes how a student organizes his/her conceptual environment. Field dependent individuals tend to follow the organization of the prevailing field. Field independent individuals tend to perceive part of the field as independent of the organization of the surrounding field as a whole. They exhibit disembedding ability (Witkin, Ottman, Raskin & Karp, 1971).

Learning Cycle - an instructional sequence used to teach a concept. The three phases in a learning cycle are: (1) concept exploration where the students explore a phenomenon and attempt to discover and formulate an explanation; (2) term invention where terms are introduced and explored that relate to the explored phenomenon; and (3) concept application phase where additional

phenomena which explore the same concepts are discussed and examined (Karplus & Thier, 1967; Lawson, Abraham & Renner, 1989).

Logical Thinking Ability - the relative ability of a student to control variables, use probabilistic, correlational, combinatorial, and proportional reasoning (Lawson, 1978).

Student's Science - is the result of the interaction of the student's naive science experiences with formal instruction as presented by the teacher and the textbook. While not in total agreement with a scientist's explanation of the world, the student's science shows an acceptable amount of agreement with it (Gilbert et al, 1985).

ASSUMPTIONS

1. Students in this study could express their understanding of the concept in this study in writing.
2. A student's written explanation of a concept could be evaluated and placed in categories of understanding by an outside evaluator.

3. The retention of a written conceptual explanation indicated that the concept had been incorporated into the student's conceptual framework while the lack of retention of a written explanation indicates that the concept had not been incorporated in the student's conceptual framework.

DELIMITATIONS

1. Subjects for this study attend school in a predominantly white, upper middle class suburb of a large, midwestern city. Any generalizations from this study will be limited to students of similar ages with similar socio-economic backgrounds.
2. The conceptual understanding profile obtained from this study will be specific to the concept used in the study (the burning candle).
3. Subjects were all exposed to the same teaching method over the same period of time. No allowances were made for individual differences.
4. Subjects had to be present on days one through three and on day 24 to be in the study.

5. Data from subjects who demonstrate an adequate understanding of the concept used in the study on the pretest were eliminated from the study.

CHAPTER II

LITERATURE REVIEW

INTRODUCTION

This chapter presents a review of the literature which supports hypotheses concerning the relationship of logical thinking and disembedding ability to the ability of students to construct conceptual understandings and to make conceptual shifts. The chapter is divided into four parts. Part I reviews the literature that deals with conceptual shifts. It includes descriptions of conceptual shifts and the conditions considered necessary for conceptual shifts to occur. Part II reviews the literature concerning the two cognitive variables used in this study, disembedding ability and logical thinking ability. Literature that supports the hypotheses that these variables affect the ability to make a conceptual shift is reviewed, research supporting the use of the instruments used in this study for each of the variables is also included. Part III summarizes the hypothesized relationships between the dependent and independent variables.

PART I.

Conceptual Shift

A concept is formed when a person learns to discriminate between stimuli and to attach different responses to different sets of stimuli (Bolton, 1972). It is the summary of the essential characteristics of a group of ideas and/or facts that epitomizes important common features or factors from a larger number of ideas (Pella, 1966). As an individual constructs a concept, he/she forms relationships between that concept and others already in place. This pattern of concepts and the interrelationships between them constitutes a cognitive structure which the individual uses to interpret and explain his/her environment. Pella (1966) presents a model which can be used to describe the various dimensions of a concept. He classifies concepts from concrete to abstract, from simple to complex, and from qualitative to comparative to quantitative (See Figure 1 on page 16).

Many studies have been done to identify and catalog science concepts held by children. It seems that children come to school with a well-developed cognitive structure which they use to explain how the world works. This body of concepts and their

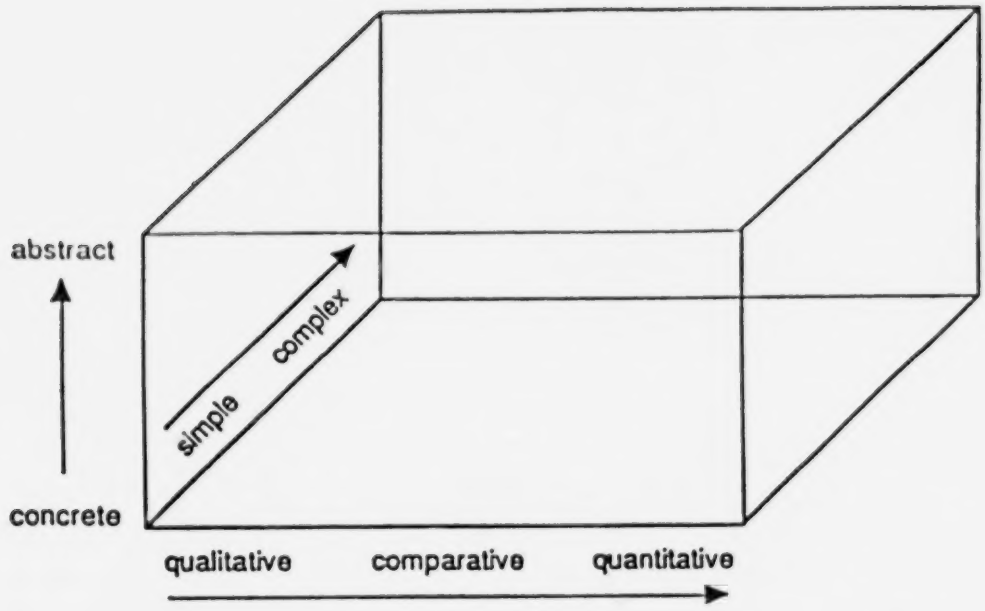


FIGURE 1

DIMENSIONS OF A CONCEPT (Pella, 1966)

relationship to each other has been documented by many researchers (Carey, 1985; Clough & Driver, 1985; Erickson, 1979, Nussbaum & Novak, 1976). Gilbert Osbourne and Fensham (1982) found that children have a logical, coherent cognitive structure concerning science. They listed the following characteristics of children's science: (1) It uses everyday language; (2) It is self-centered; (2) Nonobservables do not exist; (4) Objects have characteristics of humans or animals; (5) All objects have an amount of a physical quantity whether they consist of matter or energy. Osborne and Wittrock (1983) also examined childrens' science concepts and summarized their findings in the following statements: (1) Children hold many ideas about science concepts; (2) Children's concepts differ from scientists views; (3) Children's concepts are difficult to change; (4) Children's concepts and cognitive structures sometimes regress before they become more congruent with scientists' concepts.

Children construct concepts and build conceptual networks of the world by interacting with their environment almost from the moment of birth. Children's science is affected by their interactions with their peers, their parents and their environment.

Their gender, cognitive style, IQ, and level of logical thinking also affect their construction of a cognitive structure (Fisher and Lipson, 1986).

Science learning involves the acquisition of new information, the reorganization of existing knowledge and the discarding of cherished ideas (Hewson, 1981). Hewson explains that a new concept may be rejected or incorporated into an existing conceptual structure. When a concept is incorporated it may replace an existing concept, or it may be added to concepts already in place as an alternative concept.

A conceptual shift involves the addition of a new concept, the restructuring of existing concepts and/or the rejection of existing concepts because of reorganization or displacement. A conceptual shift occurs when new relations between concepts are represented and when new schemata come into being which allow the solution to new problems and change the solutions to old problems. Sometimes the core concepts themselves change (Carey, 1985; Champagne, Gunstone & Klopfer, 1985). The process of learning may be described in terms of a series of conceptual shifts (Strike and Posner, 1985).

When children enter school and begin their formal education, they are presented with new ideas, some of

which clash with their already developed cognitive structure. Posner, Strike, Hewson and Gerzog (1982) described this situation. They explained that if a new idea is encountered, one of two processes may occur. The child may incorporate the new ideas into his/her conceptual structure. This process is called assimilation. If the child has an explanation of the concept being taught which is not congruent with the accepted scientific explanation he/she must change his/her conceptual structure through a process called accommodation. Posner et al, (1982) describe four conditions which must be met for accommodation or a conceptual shift to occur. They are: (1) There must be dissatisfaction with the existing idea; (2) The new concept must be intelligible; (3) The new concept must be initially plausible; (4) The new concept must be fruitful.

Even if teaching methods strive to meet all four of the conditions listed above, not all students make conceptual shifts. We know that students do not make conceptual shifts easily. Targan (1987) tested 61 college students in an elementary descriptive astronomy course on their knowledge about the phases of the moon. On the pretest, six percent of the students used the correct model. After instruction 18 percent used the

correct model. Targan analyzed the conceptual changes made by the students and found that student who held definite complete incorrect models were less likely to shift to other models as a result of the instruction. Rogan (1988) saw the same results when he examined the explanation of 145 fourteen year-olds on their understanding of the concept of heat. Students with well-developed misconceptions about heat were less likely to shift to acceptable concepts about heat than were students of comparable reasoning abilities but who possessed less developed concepts of the nature of heat. Clough and Driver (1986) interviewed 84 twelve, fourteen and sixteen-year-olds and recorded their explanations of three tasks involving pressure in fluids. It was found that there was a wide range of ways in which a given phenomenon was conceptualized. The 12 and 14-year-olds were interviewed again two years later and it was found that concepts that were derived and reinforced through sensory experiences were hard to change. Hewson (1986) used clinical interviews with 40 high school students from four high schools in South Africa to examine students' ideas as to why some objects float and some objects sink. She found that the scientific concept of volume was missing in most students. She found that the students had many

alternative concepts for mass/weight, volume, and density. She also found that the relationships between the various concepts used to explain floating and sinking were varied and complex. Hashweh (1988) reviewed eight studies that described students' conceptions of motion. These studies included elementary to college-aged students. Hashweh found that student misconceptions persisted after instruction and that students compartmentalized their knowledge. They were capable of using misconceptions under certain contexts and scientifically accepted concepts under other contexts.

Cognitive development involves conceptual change. Whenever a child learns something, he/she is relating the material encountered to his/her current conceptual structure. If the child restructures his/her existing relationships between concepts or makes changes in individual core concepts, then learning is happening.

Studies have been done to determine which teaching methods cause conceptual shifts to occur. It has been shown that calling attention to students' alternative concepts makes it easier for them to make a shift. Hewson and Hewson(1983) divided black South African ninth grade students into two groups. The students in the study (n=46) were taught about mass, volume, and

density with lessons that drew attention to their misconceptions about these concepts. The control group (n=44) was taught by traditional means without attention to the misconceptions. After instruction, there was a significant difference ($p<.005$) between the two groups on a test of conceptual understanding of mass, volume, and density. Cole and Raven (1969) taught the principles of floating and sinking to 97 seventh graders, 259 eighth graders, and 38 college students. For the eighth graders and college students, teaching methods which drew attention to misconceptions were more effective ($p<.001$) in forcing the students to reject false concepts. Stavy and Berkovitz (1980) divided 77 fourth grade students into three groups. The first two were exposed to different misconceptions about temperature during their lessons on the meaning of temperature. The control group was taught about temperature without the use of the misconceptions. There was no significant difference in the scores on the pretest on temperature but on the posttest, the two groups exposed to misconceptions scored significantly higher ($p<.05$) than the control group.

Other researchers have been interested in the internal mechanisms necessary for conceptual shifts to occur. Kendler and Kendler (1962) believe that a

conceptual shift requires internal mediational processes on the part of the learner. These internal mediation processes are known collectively as metacognitive processes. Metacognition is the ability to think about one's own thinking. Kuhn, Amsel and O'Loughlin (1988) also believe that metacognition is necessary for scientific learning to occur. Through their work with students from grade three to college and with adults not in college, they have come to the conclusion that mastery of metacognition is an extended process of development. They state that the late elementary to early high school age range is the most critical time period for the development of metacognitive skills. Flavell (1985) also sees this age range as the time when considerable development in metacognition occurs. Flavell also identifies Piaget's formal operations as another name for metacognition. Lawson and Weser (1987) refer to formal operations as reflective thinking. All of these researchers see a direct relationship between metacognition and the ability to restructure science knowledge in a meaningful way.

Learning is the process of rejecting old concepts, constructing new concepts, incorporating new concepts into a framework of existing concepts which are

connected to each other by many relationships and by rearranging existing relationships between concepts. This process which is referred to in this chapter as the making of a conceptual shift is affected by many variables. The two variables which will be examined are disembedding ability and logical thinking ability.

PART II.

Disembedding Ability

Fisher and Lipson (1986) describe student characteristics which affect a child's interpretation of the physical world. Cognitive style is one important factor. Cognitive style is a multidimensional construct requiring multiple measures (Green, 1985). It refers to preferences of information processing.

Brumby (1982) summarizes assumptions made by researchers regarding cognitive style factors:

1. The measurement of abilities tends to emphasize maximum performance. Cognitive style is more concerned with typical or spontaneous behavior.

2. Ability/aptitude dimensions tend to be unipolar--scales go from little of an ability to a lot of that ability. Cognitive styles contrast the preferred mode of performance with other modes of performance. Cognitive styles are less likely to be unipolar.

3. Ability/aptitude assessement is often value-laden. That is, more of an ability is

most often better than less of an ability. For cognitive styles, circumstances determine whether it is better to use one style than another. Value is a function of the situation and the task.

4. Historically, the concept of abilities has been tied to education. Research in cognitive styles has been most often located in the psychology laboratory with the concept developing from personality theory.

5. Styles exert controls across mental functioning; abilities do not. Styles cut across task domains while abilities are specific to a particular domain of content or function.

One of the most researched dimensions of cognitive style is disembedding ability as measured by the field dependence-independence (FD/FI) construct. FD/FI measures an individual's ability to separate items or patterns from the context in which they are presented. Field independent individuals tend to perceive parts of the field as independent of the surrounding field as a whole while field dependent individuals tend to look at the field as a whole and to ignore the parts. Scores from any test of field dependence-independence form a continuous distribution. Accordingly, the designations, "field dependent," and " field independent," like the designation, "tall" and "short," are relative (Witkin, Oltman, Raskin and Karp, 1971).

Measurement along the continuum from field-dependent to field-independent measures a person's disembedding ability.

The construct of FD/FI as measured by the Rod and Frame Test (RFT) was introduced by H.A. Witkin in 1949 (Witkin, 1949). Later correlations between the RFT and the Embedded Figures Test (EFT) were seen (Witkin et al, 1971) and Witkin concluded that the EFT was also a measure of FD/FI. The EFT, an individually administered test and the Group Embedded Figures Test (GEFT), a variation of the EFT which can be administered to large groups have been used ever since to examine the relationships between disembedding ability and various other aspects of learning and personality. Witkin, Oltman, Raskin and Karp (1971) and Flexer and Roberge (1983) found that while FD/FI scores increase over time, individuals maintain their same relative standing. Morell (1976) confirmed these findings. He also found that training did not increase FD/FI scores. These results help to support the idea that the construct of field dependence-field independence is a cognitive style.

The field dependent-independent construct has been measured by a number of instruments including the Embedded Figures Test (Witkin et al, 1971) and the Rod and Frame Test (Oltman, 1968). Bergman and Englebreckstron (1973) found that the EFT and the RFT only shared 4-16% variance. Linn and Kylonnen (1981) gave 60 high school students a battery of 31 tests which claimed to measure components of field dependent/independent cognitive style. Factor analysis and varimax rotation placed the tests in two clusters. Linn and Kylonnen interpreted these results to mean that the two clusters measured two different components of the field dependence-independence cognitive style. They concluded that the cluster, which included the rod and frame test and the bottles test, measured the ability to select relevant strategies from salient but irrelevant strategies in a familiar situation while the other cluster, which included the embedded figures test, measured cognitive restructuring ability; the ability to disembedded relevant information from complex situations. This research supports the use of the GEFT as a measure of disembedding ability.

Many studies have made connections between FD/FI and science learning. Some have made direct relationships between science achievement and FD/FI while most of them have connected FD/FI to success in science by making connections between FD/FI and logical reasoning skills.

Lawson (1983) found that science achievement on a unit of biological evolution for nonscience major college students (n=96) was predicted by logical thinking and disembedding ability. Disembedding ability was found to be the consistent predictor ($p<.01$) of overall achievement ($p=.01$). Shymansky and Yore (1980) also found that achievement in science was related to field-independence. They tested 77 undergraduate elementary education majors using individual interviews to determine logical thinking skills and the GEFT to determine field dependence/independence. They found that field-independent subjects consistently achieved higher scores on tests and quizzes in a general science class than did the field-dependent subjects. In a study of 4th, 5th and 6th graders with IQ's over 132, Saurenman and Michael (1980)

found that the high achievers were more field independent than the gifted field-dependent students.

More studies connect science achievement and FD/FI through the relationship of FD/FI to logical thinking skills. Stuessy (1989) showed that field dependence-independence was a significant aptitude needed for logical thinking. She found that, after age and IQ, FD/FI was the next most important predictor of logical thinking skills in a group of 7th and 11th graders (n=230). Linn and Pulos (1983) showed that in a sample of 7th, 9th and 11th graders the FD/FI was related to logical thinking skills. Lawson (1976) tested 25 sixth-graders and found that FD/FI was a predictor of the development of formal reasoning. Collings (1984) found that field independence was associated with an increase in logical thinking in 11 and 12 year-olds.

Other studies have narrowed their scope to examine one of the logical thinking skill, proportional reasoning, and to examine its relationship to FD/FI and to science achievement. Ronning et al. (1984) found that field independent students were better problem solvers than field

dependent students. The problems they were given to solve involved proportional reasoning skills. Falls and Voss (1985) studied 77 high school chemistry students. They found that field-independent students were better at solving proportional problems and that proportional reasoning was significantly correlated to success in chemistry. Dozier (1985) examined proportional reasoning abilities and science achievement in junior high school students. He found that there was a positive relationship between the two. Niaz (1989), in a study of 318 high school science students, found that there was a high correlation ($r = .50$, $p=.001$) between nine proportional reasoning tasks and the GEFT.

It has been hypothesized in this study that disembedding ability as measured by the GEFT is significantly related to the ability to make a conceptual shift. The literature does not contain any examinations of this relationship. As can be seen in the preceding pages there is research supporting other relationships which connect disembedding ability to the ability to make a conceptual shift. For purposes of this study it is assumed that children do not always form

acceptable concepts to explain the world around them. It is also assumed that students who exhibit high levels of achievement in science do hold a large number of adequate concepts. Therefore, students who are high achievers must make a number of conceptual shifts when they replace their misconceptions with more acceptable explanations. What part does disembedding ability play in this task? Disembedding ability is the ability to restructure a perceptual field, to analyze the pieces and put them together in a new way. Logical thinking skills, proportional reasoning, in particular, demand that the student be able to do this. A student who shows a high disembedding ability is better able to think logically and may prefer to think in that mode. That student should have an easier time restructuring an existing concept.

Several studies have suggested that field dependence-independence scores and general fluid intelligence scores account for the same source of variance in science achievement (Latsch and Linn, 1980; Lawson and Wollman, 1977; Niaz and Lawson, 1985; Sweyter and Michael, 1982). Fluid intelligence consists of the tasks requiring

grasp of complex relationships in nonverbal material. Other have examined tests of fluid intelligence and FD/FI and concluded that FD/FI is related to the analytical portion of fluid intelligence but not to verbal ability.

Logical Thinking Ability

Inhelder and Piaget (1958) described the cognitive developmental level called "formal operations." They described a formal operational individual as a person with the ability to search for and evaluate evidence to support or reject hypothetical causal propositions. Lawson (1978) broke this reasoning level down into five cognitive processes. These five processes were: proportional reasoning, probabilistic reasoning, the control of variables, correlational reasoning and combinatorial reasoning. This collection of cognitive skills has been called advanced reasoning (Lawson, 1982), reflective thinking (Lawson and Weser, 1988), formal operations (Inhelder and Piaget, 1958), scientific reasoning (Levine and Linn, 1977; Stuessy, 1989) and metacognitive thinking (Nisbett and Ross, 1988).

For this study, a student's ability to use these five processes will be called logical thinking skills.

Lawson's five processes are all necessary for thinking in science. Isolation and control of variables is the ability to determine which of the factors involved in a problem can vary and the ability to examine each variable while keeping the other constant. Combinatorial reasoning consists of the ability to determine all of the possibilities inherent in a problem so that all of them can be examined. Combinatorial reasoning allows the individual to isolate all of the possible variables and all of the possible combinations of variables. Correlational reasoning is the ability to estimate the relationship and the strength of the relationship between two variables. Probabilistic reasoning is the ability to identify a set of phenomena as chance events or as non-chance events. It involves the ability to determine whether events are predictable or nonpredictable. Proportional reasoning is the ability to see the relationship between two ratios. Qualitative proportional reasoning (i.e., foot is to shoe as _?_ is to

glove) precedes mathematical proportional reasoning, which is a statement about the equality of two ratios (i. e., a/b = c/d).

Numerous studies have shown that logical thinking skills serve as a predictor for the understanding of science concepts. Shayer and Wylam (1981) tested 161 ten through thirteen-year-olds on their understanding of the concepts of heat and temperature. They found a correlation of .60 between their score on a test of logical thinking and their understanding of these concepts. Chandron, Treagust and Tobin (1987) studied the relationship of logical thinking skills and disembedding ability and their effect on chemistry achievement. They found that logical thinking skills were significantly related ($p<.001$) to achievement. A path analysis of their data indicated that logical thinking affected achievement directly and indirectly by its effect on prior knowledge which also had a direct effect on achievement. Mensha, Erickson and Gaskell (1987) used path analysis to examine the relationship of chemistry achievement and logical thinking in 328 high school chemistry students. They found that logical thinking skills,

proportional reasoning in particular, did show a significant effect on chemistry achievement. Krajcik and Haney (1987) compared logical thinking skills to chemistry achievement in 170 eleventh and twelfth graders. Students with greater logical thinking skills showed greater chemistry achievement. A further analysis of the data showed that 18 of the 31 discriminators involved proportional reasoning while only three of the 49 nondiscriminators did. Lawson and Thompson (1987) studied 131 seventh graders looking for relationships between the number of misconceptions, reasoning ability and field dependence-independence after formal instruction. Reasoning ability was found to be inversely related ($p=.001$) to the number of misconceptions but field dependence-independence was not.

In addition to direct relationships to science achievement, logical thinking skills have also been related to science process skills. Five hundred students in grades seven through twelve were given a test of logical thinking skills and a test of integrated science process skills. There was a strong correlation ($r=.73$) between the two tests. Tobin and Caple (1982) studying 13 intact

classes of seventh and eighth graders, compared logical thinking skills to science process skills. Twenty-six percent of the variance was shared by the two variables. Glasson (1989) found that ninth graders' (n=59) scores on the TOLT, a logical thinking test were the best predictor ($p<.01$) of problem solving skills in science. Prior knowledge was the second best predictor, and teaching method was the third. Fifty-three percent of the variance in problem solving was accounted for by these three variables. Chandron, Treagust and Tobin (1987) found that a test of logical thinking skills was significantly related ($p<.001$) to the laboratory application skills of chemistry students while prior knowledge, disembedding ability and memory were not. Niaz and Lawson (1985) tested 25 nonmajor science undergraduates and found a relationship between logical thinking skills and the ability to balance chemical equations. They found that logical thinking ability was the best predictor of the ability to balance a simple chemical equation ($R=.50$, $p<.05$). Inclusion of mental capacity and field dependence/independence increased the

Multiple R to only .52, which was a nonsignificant increase.

Another way to examine the relationship of logical thinking and achievement in science is to look at the relationship of logical thinking to misconceptions. Renner, Abraham, Grzbowski and Marek (1990) looked at five levels of understanding of four physics concepts in 257 eighth graders. They discovered that students with greater logical thinking skills had fewer misconceptions. Lawson and Thompson (1988) studied seventh graders in five sections of a life science course. They compared students' logical thinking skills, mental capacity, verbal intelligence, and disembedding ability to their understanding of evolution and genetics concepts after a one month unit on those concepts. An analysis of variance showed that only logical thinking level had a significant ($p<.05$) relationship to the number of misconceptions held. Students operating at higher logical thinking levels held fewer misconceptions. In 1988, Lawson and Weser tested 954 nonbiology major biology students on their beliefs about the soul, teleology, orthogenesis, reductionism and special

creation. These students were also given a test of logical thinking skills. There was a significant relationship ($p<.05$) between logical thinking and nonscientific views on six of the 26 items on the test of scientific beliefs. Students with higher levels of logical thinking held fewer nonscientific views. Eleven other items showed a difference which did not prove to be statistically different.

One study had analyzed the relationship between the ability to make a conceptual shift and logical thinking skills. Lawson and Weser (1988), in a study described in the previous section, examined the beliefs of 954 college students before and after a 14-week biology unit. Students with higher scores on the test of logical thinking shifted away from nonscientific beliefs on each of the 26 items on the test. Students with low scores shifted away from nonscientific beliefs on only two areas of the test.

While only one empirical study has been reported, papers have been written on the relationship of logical thinking to the ability to make a conceptual shift. Logical thinking, which consists of the five processes described in a

previous section, is metacognitive in nature (Nisbett and Ross, 1980; Flavell, 1985). It is an abstract-derivative type of thinking in which the individual monitors his/her own progress. This aspect of logical thinking is very important for thinking and problem solving in the sciences. Nisbett and Ross (1980) describe three keys to logical or scientific thinking. They are: (1) the ability to think about a theory; (2) the ability to encode and represent evidence to be evaluated as a distinct entity; and (3) the ability to bracket or set aside acceptance or rejection of a theory. All of these abilities depend on the ability to think about one's own cognition. Since logical thinking is necessary for metacognition, it is necessary for thinking in science. Lawson and Thompson (1988) describe three conditions for overcoming misconceptions in science. They are: (1) the awareness of the scientific concept; (2) the awareness of how evidence supports the concept; (3) awareness of how evidence contradicts the misconceptions. In order to meet these three conditions, a student must possess sound logical thinking skills.

For many years, logical thinking skills as described by Piaget were measured using individual clinical interview techniques. Lawson (1978) outlines some early attempts in the 1960's and 1970's to develop a reliable and valid group test of logical thinking ability. Some were strictly paper and pencil tests which eliminated the need for equipment. Other tests provided for the use of equipment which was manipulated by each subject. This format was very time consuming and made large group testing difficult. The next advance was to show the test group a demonstration and ask them questions about the demonstration. Lawson (1978) took this lead and developed a 15 item test. The test consisted of 15 demonstrations. The subjects watched each demonstration and then picked the best answer from a list of possible answers for each question. They then had to explain in their own words why they picked that answer. Items were scored as correct only if the correct box was checked and an adequate answer was given for the selection. The test was scored from 0 - 15. Reliability for this test was computed to be .78.

Tobin and Caple (1981) tried to improve on the Lawson format. They retained the demonstrations for each of the questions. They also retained the list of possible answers but they eliminated the need to write a justification for the answer. Instead, they presented a list of possible justifications for each answer so that the subject would have to watch a demonstration, pick an answer from a list of possible answers and pick a justification for that answer from a list of possible justifications. The last two items on the test were an exception to this rule. The last two questions which measure combinatorial reasoning require the subject to make a list of all of the possible combinations which can be made of three and four variables. The other way that Tobin and Caple modified Lawson's test format was to use only ten items on their test. They used two items for each of the following reasoning skills: combinatorial reasoning, isolation and control of variables, correlational reasoning, probabilistic reasoning, and proportional reasoning.

The internal consistency reliability for Tobin and Caple's Test of Logical Thinking (TOLT)

was .85. A moderately strong one factor solution obtained from factor analysis of performance on the 10 items suggested that the items were measuring a common underlying dimension. The TOLT has been used in research around the world and in elementary, secondary, and college level studies (Tobin, 1988).

PART III.

Hypothesized Relationships Between Disembedding Ability, Conceptual Understanding, and Conceptual Shifts

Based on research described in this chapter, students who score higher on a test of field independence should show a better understanding of a science concept than students who score lower because they are better able to pick out the relevant bits of information from complex contexts.

Students who score higher on a test of field independence should be better able to deal with concepts in conflict with their own misconceptions. As a result, students who score higher on the GEFT should be more likely to make

conceptual shifts when presented with information which conflicts with their misconceptions.

Hypothesized Relationships Between Logical Thinking Ability, Conceptual Understanding, and Conceptual Shifts

Based on research described in this chapter, students who exhibit greater logical thinking skills should hold fewer misconceptions than students with lesser logical thinking skills. Students who make conceptual shifts from a less adequate to a more adequate understanding of a scientific phenomenon should have greater logical thinking skills than those students who do not make conceptual shifts after exposure to instruction.

CHAPTER III

METHODS AND PROCEDURES

This chapter is divided into six sections. The first section contains a description of the pilot study. The second section describes the selection of the population used in the study, while sections three and four describe the design and the instruments used in the study. Section five describes the statistical procedures used to test the hypotheses and section six describes the treatment and timeline for the study.

PILOT STUDY

There were several objectives for the pilot study which was conducted in the spring of 1989 with eighth graders at Perry Middle School (n=94). In the pilot project, four potentially useful instruments (described on page 46) were administered and the learning cycle approach was used to determine which activities were appropriate for teaching the concepts involved. One purpose of the pilot study was to find a concept that many middle school students did not understand and to find out how many of them could be made to change their concept during a three-day lesson on the concept.

The pilot study was also used to look for differences in the profiles of the students who changed their conceptual understanding compared to those who did not.

The study showed that the candle in a jar phenomenon was not understood by a majority of eighth graders and that it could be successfully taught to some of them (See Table 1 on page 46). Table 2 on page 47 summarizes the results obtained by using these instruments in the pilot study. The results of the pilot also showed that logical thinking ability as measured by the TOLT and disembedding ability as measured by the GEFT appeared to be different in the groups of students who made conceptual shifts compared to those who did not (See Table 3 on page 48).

The Nowicki-Strickland Locus of Control Test (Nowicki & Strickland, 1973) was administered along with the TOLT and the GEFT. This measure was dropped from the final study because of its low reliability (Cronbach's alpha = .64) and its lack of correlation with the making of a conceptual shift.

The Test of Cognitive Skills scores were obtained from student files. This measure was dropped from the final study because the scores were heavily skewed toward the maximum score of 99.

Table 1

LEVEL OF UNDERSTANDING OF THE BURNING CANDLE PHENOMENON ON FOUR CONSECUTIVE TESTS IN THE PILOT STUDY

	NO CONCEPT	NAIVE CONCEPT	PARTIAL CONCEPT	ADEQUATE CONCEPT
Time 1	10%	82%	5%	2%
Time 2	4%	89%	5%	1%
Time 3	2%	42%	22%	29%
Time 4	3%	44%	49%	3%

Table 2

DESCRIPTIVE STATISTICS AND RELIABILITIES
OF INSTRUMENTS USED IN THE PILOT STUDY

VARIABLE	CASES	MEAN	SD	RANGE	RELIABILITY
LOC	93	7.85	3.22	1-16	.62
GEFT	91	10.54	4.75	1-18	.88
TOLT	92	3.39	2.73	0-10	.80
TCS	74	74.43	21.37	7-99	
AN	73	66.05	24.74	5-99	
MEM	73	69.22	24.09	8-99	
VER	74	75.80	21.94	17-99	
CON1	90	2.00	.50	1-4	
CON2	94	2.03	.37	1-4	
CON3	90	2.78	.90	1-4	
CON4	85	2.54	.62	1-4	
SHIFTA	85	.16	.37		
SHIFTB	85	.49	.50		
SHIFTC	80	.53	.50		

Table 3

MEANS OF THE PILOT INSTRUMENTS FOR THE GROUP OF STUDENTS WHO MADE CONCEPTUAL SHIFTS AND FOR THE GROUP OF STUDENTS WHO DID NOT MAKE CONCEPTUAL SHIFTS IN THE PILOT STUDY

VARIABLE	CASES	NO SHIFTA (0)	CASES	SHIFTA (1)
LOC	63	7.23	14	8.86
GEFT	63	10.98	13	10.84
TOLT	63	3.54	14	3.36
TCS	53	75.32	11	69.72
VARIABLE	CASES	NO SHIFTB (0)	CASES	SHIFTB (1)
LOC	39	8.13	39	7.85
GEFT	40	9.80	36	11.23
TOLT	40	3.20	39	3.82
TCS	36	71.14	26	76.54
VARIABLE	CASES	NO SHIFTC (0)	CASES	SHIFTB (1)
LOC	33	8.15	41	7.59
GEFT	34	9.79	39	11.31
TOLT	34	3.32	40	3.78
TCS	30	71.73	29	75.90

Results of the pilot project led to the identification of two instruments as probable indicators of conceptual understanding and shifting in eighth graders and the establishment of a protocol for the learning cycle and associated conceptual understanding tests that were feasible and appropriate for eighth graders in the final study.

SELECTION AND DESCRIPTION OF SUBJECTS

Subjects for this study were taken from the members of an eighth grade interdisciplinary team at McCord Middle School in a suburb of Columbus, Ohio. Students at this school are randomly assigned to one of the two eighth grade teams. These students are grouped for classes in English, social studies, science, and mathematics. English, science, and social studies are taught in heterogeneous groups. A group of the students characterized by higher mathematics ability is selected out for an algebra class while the others take an eighth grade pre-algebra course. All of the members of the interdisciplinary team who returned their permission slips and who were present on days one through three and on day 24 participated in this study (n=55).

DESIGN

This study was descriptive in nature. Students who returned their permission slips were given the TOLT and the GEFT during a two-day period prior to the three day instructional period. On day one of the instructional period the students were shown the burning candle phenomenon and asked to explain it on a pretest. The rest of day one and the next two days were used for instruction following the learning cycle format (See student packet in Appendix A). All classes were taught by the investigator. On day three, after the instruction was completed, all students took the posttest on which they wrote a new explanation for the burning candle phenomenon. Twenty-one days later on day 24, the students were shown the burning candle again and they were given a follow-up test on which they were asked to explain the phenomenon again. Subjects for the study were the students (n=55) who took the TOLT and the GEFT and who did not have an adequate explanation for the burning candle on the pretest and who were present on days one, two, three and 24.

The students' scores on the TOLT and the GEFT of the students who showed an increase in conceptual understanding were compared to the scores of the group

of students who did not show an increase in conceptual understanding. Students whose conceptual understanding scores as measured on the CUF increased by one or more units from the pretest to the posttest (Shift A), from the posttest to the follow-up test (Shift B), or from the pretest to the follow-up test (Shift C) were considered to have made a conceptual shift. A CUF score of one was given for no written explanation, a score of two was given for a naive explanation, a score of three was given for a partially correct explanation, and a score of four was given for an acceptable explanation.

Scores of conceptual understanding were also examined for the presence of a positive correlation between the TOLT score and level of conceptual understanding and between the GEFT and the level of conceptual understanding.

A multivariate analysis of variance (MANOVA) was performed to determine any significant differences between the group that made a conceptual shift and the group that did not make a conceptual shift. The MANOVA procedure was chosen to protect against a Type I error, the possibility of finding a significant difference by chance. In hypotheses III and IV there were two dependent variables (TOLT and GEFT) which were to be

analyzed. As the number of comparisons increased the chance of making a Type I error increased so by looking at the GEFT and TOLT simultaneously, the chance of making a Type I error was decreased.

INSTRUMENTS

Test of Logical Thinking (TOLT)

The Test of Logical Thinking (TOLT) developed by Tobin and Caple (1981) is a pencil and paper instrument that measures five reasoning abilities which have been identified by Lawson (1978) as being important to science learning. The TOLT consists of ten problems: two measuring proportional reasoning; two measuring probabilistic reasoning; two measuring the control of variables; two measuring correlational reasoning; and two measuring combinatorial reasoning. Each problem has a set of alternative answers followed by a set of justifications. Both the answer and the justification must be correct for the item to be scored as correct. The maximum score is ten and the minimum score is zero.

The test, which can be administered in a 45-minute class period has been used successfully from grade six on up (Newton, 1982; Tobin and Caple, 1982; Helseth, 1984; Padilla, Okey and Dillashaw, 1983).

These researchers have reported reliability in the .80 to .85 range. The reliability of the TOLT in the pilot study was .80 as measured using Cronbach's alpha (Table 3). Appendix B is a copy of the question and answer sheets for this test.

Group Embedded Figures Test (GEFT)

The cognitive style labeled field dependence was measured using the Group Embedded Figures Test (Witkin et al., 1971) This timed test consists of 18 geometric shapes. The subjects are asked to look at a shape on the back of the test and then to trace the same shape which is hidden in each of the eighteen items on the test. The hidden shape is the same size and oriented in the same direction on the back of the test as it is in the test item. The time allowed for this test is 18 minutes. The maximum score on this test is 18 and the minimum test is zero. The reliability of this test in the pilot study was .88 (Cronbach's alpha) (Table 3). Appendix C is copy of the sample questions and answers for this test.

Conceptual Understanding Form (CUF)

The subjects were asked to answer two questions on three different occasions. The same questions were asked each time. They were as follows: Why did the candle go out? and, Why did the water rise in the jar? Each response was scored in the following manner:

1. No explanation = 1 point
2. Naive explanation = 2 points
3. Partial explanation = 3 points
4. Adequate explanation = 4 points

Naive explanations were any explanations which were not correct such as " The candle sucked up the water." "The jar squeezed the water and it rose in the jar." " The water rose in the jar to take the place of the oxygen that was used up by the candle."

Partial explanations contained acceptable information but were missing some of the parts deemed necessary for an adequate explanation. The most common explanation was that the candle heated the air in the jar. The air expanded and then contracted. This contraction then lowered the air pressure in the jar and the water was pushed into the jar by the greater

pressure on the outside. A majority of the explanations omitted the information about the gases escaping from the bottom of the flask.

An adequate explanation had to possess all of the following parts:(1) The candle heated the air in the jar; (2) The air expanded and increased the air pressure inside the jar so that some of the air escaped from the bottom of the jar; (3) The air in the jar cooled and contracted, lowering the air pressure inside; (4) Since the air pressure on the outside of the jar is now greater, it pushes the water up into the jar until the air pressure inside and outside is the same. Appendix C is a detailed explanation of the scientific principles shown in the burning candle phenomenon.

The reliability of the ratings was determined by having a panel of three judges score a random sample of 50 of the student responses. The judges were three high school science teachers who were given both verbal and written instructions about the salient features of the burning candle phenomenon and about the levels of understanding as defined in this study. Each teacher was given a packet with the same 50 random samples of explanations from the students in the study. Each judge rated the explanations from one to four. The

judges' and the investigator's classifications of each conceptual understanding items were subjected to a Friedman's analysis of variance using the SPSSX subprogram RELIABILITY. Friedman's analysis of variance is a two-way analysis of variance used to determine the variance of ranked data. The statistics from this analysis were used to calculated an internal consistency reliability (Cronbach's alpha). Appendix D is a copy of the CUF.

STATISTICAL ANALYSIS

Raw data from all of the instruments were collected on coding sheets and placed on the Wylbur System at The Ohio State University. All analyses were conducted using appropriate subprograms in the Statistical Package for the Social Sciences X (1988).

Descriptive Statistics and Reliability of Instruments

The frequencies and percentages of levels of conceptual understanding on day one, three, and twenty-four were calculated. Means and standard deviations were calculated for the level of conceptual understanding, TOLT, GEFT, Shift A, Shift B, and Shift C.

The internal consistency (Cronbach's alpha) of the TOLT and the GEFT were calculated using the SPSSX Subprogram, RELIABILITY. The internal consistency for the TOLT was .74. The internal consistency for the GEFT was .86. The internal consistency (Cronbach's alpha)of the CUF was calculated using a Friedman's analysis of variance from the SPSSX Subprogram RELIABILITY. The internal consistency was .89. See Table 4 on page 58.

Techniques Used to Test the Hypotheses

Hypothesis I.

There will be no significant correlation between the level of logical thinking as measured by the TOLT and the level of conceptual understanding on the:

a. pretest
b. posttest
c. follow-up test.

The Pearson Correlation coefficients were calculated using the SPSSX Subprogram PEARSON CORR for hypotheses Ia, Ib and Ic.

TABLE 4

RELIABILITY DETERMINATION OF THE CONCEPTUAL UNDERSTANDING FORM (CUF): FRIEDMAN'S ANALYSIS OF VARIANCE
4 RATERS BY 50 ITEMS

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	CHI-SQUARE	PROB.
BETWEEN RATERS	47.68	52	.92		
WITHIN RATERS	18.75	159	.12		
BETWEEN MEASURES	1.98	3	.66	16.76	.0008
RESIDUAL	16.77	156	.11		
TOTAL	66.43	211	.31		

GRAND MEAN = 2.55

COEFFICIENT OF CONCORDANCE = .030

RELIABILITY OF COEFFICIENTS

ALPHA = .88 4 ITEMS STANDARDIZED ITEM ALPHA = .89

Hypothesis II.

There will be no significant correlation between disembedding ability as measured by the GEFT and the level of conceptual understanding on the:

a. pretest
b. posttest
c. follow-up test.

The Pearson Correlation coefficients were calculated using the SPSSX Subprogram PEARSON CORR for hypotheses IIa, IIb, and IIc.

Hypothesis III

There will be no significant difference in the mean score on the TOLT for the group of students who make a conceptual shift compared to the mean score of the group of students who do not make a conceptual shift at the following times:

a. pretest to posttest (Shift A)
b. posttest to follow-up test (Shift B)
c. pretest to follow-up test (Shift C)

A multivariate analysis of variance using the SPSSX subprogram MANOVA was performed to test hypotheses IIIa, IIIb, and IIIc.

Hypothesis IV.

There will be no significant difference in the mean score on the GEFT for the group of students who make a conceptual shift compared to the mean score of the group of students who do not make a conceptual shift at the following times:

a. pretest to posttest (Shift A)
b. posttest to follow-up test (Shift B)
c. pretest to follow-up test (Shift C)

A multivariate analysis of variance using the SPSSX Subprogram MANOVA was performed to test hypotheses IVa, IVb, and IV.

DESCRIPTION OF TREATMENT

Two weeks before the study began, permission letters were distributed by the social studies teacher on the team to members of Team 8-1, the interdisciplinary team at McCord Middle School.

One week before the study began, students who had returned the signed permission letters were given the GEFT and TOLT on two consecutive days during their social studies class. Appendix E is a copy of the permission letter.

On day one of the study, all of the students on Team 8-1 were presented with the burning candle

phenomenon as part of their regular daily science class. This event is one that is used in many science classes in elementary and junior high school. A burning candle was placed in a small shallow pan filled with water. A jar or flask was placed over the candle. After a few seconds the candle flame went out and the water rose in the container. Two questions were asked. The first was: Why did the candle go out?" The other question was: " Why did the water rise in the flask?" Appendix C contains a detailed explanation of the principles involved in the burning candle phenomenon.

All students wrote an explanation of the event. The only explanations used in the study were those of the students who had returned the permission letter and had taken the TOLT and the GEFT.

On days two and three, all of the students on the team participated in the activities described in the student booklet. (Appendix D). All of the students wrote a new explanation of the burning candle event at the end of the third day. Again, the only explanations used in the study belonged to the students who had returned the permission letter and who had taken the TOLT and he GEFT.

On day 24, students were again presented with the burning candle phenomenon at the beginning of their

regular science lesson. This time span of three weeks from the posttest to the follow-up test was used to see how many of the students would retain the concept they had constructed during the three-day lesson. It was assumed that students who had incorporated the explanation they had written on the posttest into their cognitive structure would retain that explanation 21 days later while students who had only remembered the explanation but had not incorporated it into their cognitive structure would not remember that explanation over that time span. All explanations were collected, but only the explanations of students who had participated in the first part of the study were used. Figure 2 on page 63 is a diagram of the design of the study. Table 5 on page 64 is a schedule of events for the study.

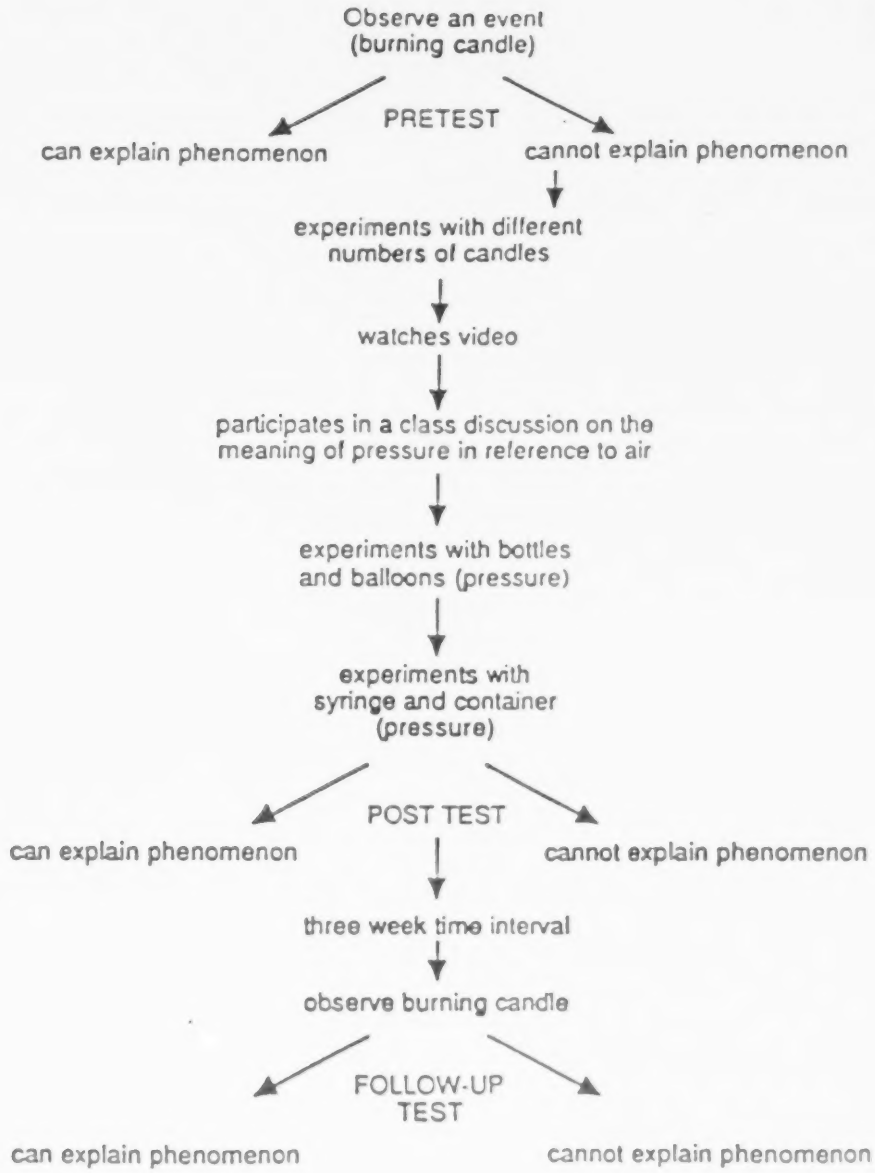


Figure 2

DESIGN OF THE STUDY

Table 5

SCHEDULE OF EVENTS

TIME	ACTIVITY	INSTRUMENT
1 week before instruction	permission letters distributed	
5 days before instruction	group administered test (25 minutes)	GEFT
4 days before instruction	group administered test (45 minutes)	TOLT
Day 1	demonstrate burning candle phenomenon and begin three day lesson (50 minutes)	pretest CUF
Day 2	continue three day lesson (50 minutes)	
Day 3	finish three day lesson	posttest CUF
Day 24	demonstrate burning candle phenomenon	follow-up CUF

CHAPTER IV

ANALYSIS OF DATA

INTRODUCTION

This chapter is divided into four sections. The first section describes the subjects and descriptive statistics of the study. The second section lists the findings concerning the four research hypotheses. The third section contains a qualitative analysis of the students' explanations of the burning candle phenomenon and the last section summarizes the findings of the study.

DESCRIPTION OF SUBJECTS

The 110 students on Team 8-1 at Perry Middle School in Worthington, Ohio were targeted for participation in this study. Seventy-one of the students returned their permission letters (See Appendix F for a copy of the permission letter.). Sixty-six of these students were present on day one of the study. One student was eliminated on the first day

because she showed a complete understanding of the burning candle phenomenon. Sixty-four of the original 67 were present on days two and three. Another nine students were not present on day 24 for the last testing. Altogether ten students were lost over the duration of the study. Data from the 55 students who were given the TOLT, GEFT and who were present during all three lessons and on day 24 were included in the investigation.

Means, standard deviations, ranges and reliabilities for the GEFT, TOLT, and CUF are shown in Table 6 on page 67. The means of the TOLT and the GEFT for the group of students who made conceptual shifts and for the group than did not were calculated. They are shown in Table 7 on page 68.

TABLE 6

DESCRIPTIVE STATISTICS AND RELIABILITIES
FOR THE INSTRUMENTS USED IN THE STUDY

VARIABLE	CASES	MEAN	SD	RANGE	RELIABILITY
GEFT	55	9.98	4.12	1-18	.86
TOLT	55	2.85	2.42	0-9	.73
PRETEST CUF	55	1.87	.55	1-3	
POSTTEST CUF	55	2.58	.60	2-4	
FOLLOW-UP CUF	55	2.58	.63	2-4	
SHIFT A	55	.72	.45	0-1	
SHIFT B	55	.15	.35	0-1	
SHIFT C	55	.58	.50	0-1	

TABLE 7

MEANS AND STANDARD DEVIATIONS ON THE GEFT AND TOLT FOR THE GROUP OF STUDENTS WHO MADE CONCEPTUAL SHIFTS AND FOR THE GROUP OF STUDENTS WHO DID NOT MAKE CONCEPTUAL SHIFTS

VARIABLE	NO SHIFT			SHIFT		
SHIFT A	cases	mean	sd	cases	mean	sd
GEFT	15	9.60	3.94	40	10.13	4.20
TOLT	15	1.60	2.17	40	3.33	2.37
SHIFT B						
GEFT	47	9.96	3.93	8	10.13	5.33
TOLT	47	2.81	2.43	8	3.13	2.53
SHIFT C						
GEFT	23	9.61	3.40	32	10.25	4.58
TOLT	23	2.09	2.35	32	3.40	2.34

RESEARCH HYPOTHESES

Hypothesis I.

There will be no significant correlation between the level of logical thinking as measured by the TOLT and the level of conceptual understanding on the

a. pretest
b. posttest
c. follow-up test.

Ia. The correlation coefficient between the TOLT and level of conceptual understanding on the pretest was -.13 ($p<.36$). The null hypothesis could not be rejected.

Ib The correlation coefficient between the TOLT and level of conceptual understanding on the posttest was .29 ($p<.05$). The null hypothesis was rejected.

Ic. The correlation coefficient between the TOLT and level of conceptual understanding on the follow-up was .36 ($p<.01$). The null hypothesis was rejected.

Based on these findings, hypothesis Ia could not be rejected but hypotheses Ib and Ic could be (See Table 8 on page 70.) These results indicated that logical thinking ability as measured by the TOLT had a significant relationship to students' ability to construct an acceptable conceptual understanding of the

burning candle phenomenon after instruction. The results also indicated that the TOLT had a significant relationship to students' ability to retain an acceptable conceptual understanding during the 21-day period until the follow-up test. The fact that Hypothesis Ia was rejected indicated that students' initial conceptual understanding of the burning candle phenomenon had no significant relationship to their logical thinking ability.

TABLE 8

CORRELATION COEFFICIENTS FOR THE TOLT, GEFT AND LEVELS OF UNDERSTANDING AS MEASURED BY THE CUF ON THE PRETEST, POSTTEST, AND FOLLOW-UP TEST

	GEFT	TOLT	PRETEST	POSTTEST	FOLLOW-UP
GEFT	1.00	.27*	.11	.15	.16
TOLT		1.00	-.13	.29*	.36**

* P < .05 ** P< .01

Hypothesis II.

There will be no significant correlation between disembedding ability as measured by the GEFT and the level of conceptual understanding on the

a. pretest
b. posttest
c. follow-up test.

IIa The correlation coefficient between the GEFT and the level of conceptual understanding on the pretest was .11 ($p<.40$). The null hypothesis could not be rejected.

IIb. The correlation coefficient between the GEFT and the level of conceptual understanding on the posttest was .15 ($p<.28$) . The null hypothesis could not be rejected.

IIc. The correlation coefficient between the GEFT and the level of conceptual understanding on the follow-up test was .16 ($p<.24$). The null hypothesis could not be rejected.

These results indicated that disembedding ability as measured by the GEFT was not significantly related to students' abilities to construct an acceptable conceptual understanding of the burning candle phenomenon.

Hypothesis III.

There will be no significant difference in the mean score on the TOLT for the group of students who make a conceptual shift compared to the mean score of the group of students who do not make a conceptual shift at the following times:

a. pretest to posttest (Shift A)
b. posttest to follow-up (Shift B)
c. pretest to follow-up (Shift C)

IIIa. A univariate F test showed that the F value for the effect of the TOLT on the ability to make a conceptual shift at Shift A was 6.01 ($p<.02$). The null hypothesis was rejected.

IIIb. A univariate F test showed that the F value for the effect of the TOLT on the ability to make a conceptual shift at Shift B was .11 ($p<.73$). The null hypothesis could not be rejected.

IIIc. A univariate F test showed that the F value for the effect of the TOLT on the ability to make a conceptual shift at Shift C was 4.18 ($p<.05$). The null hypothesis was rejected.

Results of the analysis indicated that logical thinking ability as measured by the TOLT was related to the ability of students to make a conceptual shift

after a three day instruction period. (See Table 9 on page 76.) There was no significant relationship between logical thinking ability and a conceptual shift after the 21-day period between the posttest and the follow-up test. This is reasonable because there was no instruction during this period. The purpose of the wait was to see how many students shifted back to a lower level of understanding. The fact that there was a significant difference between the logical thinking ability of students who did and did not make a conceptual shift from the pretest to the follow-up test indicated that the conceptual shift may have been incorporated into the students' conceptual framework on more than a temporary basis.

Hypothesis IV.

There will be no significant difference in the mean score on the GEFT for the group of students who make a conceptual shift compared to the mean score of the group of students who do not make a conceptual shift at the following times:

a. pretest to posttest (Shift A)
b. posttest to follow-up (Shift B)
c. pretest to follow-up (Shift C)

IVa. A univariate F test showed that the F value for the effect of the GEFT on the ability to make a conceptual shift at Shift A was .17 ($p<.68$). The null hypothesis could not be rejected.

IVb. A univariate F test showed that the F value for the effect of the GEFT on the ability to make a conceptual shift at Shift B was .01 ($p<.92$). The null hypothesis could not be rejected.

IVc. A univariate F test showed that the F value for the effect of the GEFT on the ability to make a conceptual shift at Shift C was.32 ($p<.57$). The null hypothesis could not be rejected.

Results of the multivariate analysis of variance indicated that disembedding ability as measured by the GEFT was not significantly related to students' abilities to make a conceptual shift. It should be noted that the average GEFT for the group of students who made conceptual shifts was higher for shift A, B, and C than the average GEFT score for the group of students who did not make a conceptual shift. It is possible that the GEFT acts on the ability to make a conceptual shift through its influence on logical thinking skills. If the GEFT had an indirect influence

on the ability to make a conceptual shift it would not show a significant direct relationship.

SUMMARY OF FINDINGS ON THE HYPOTHESES

1. Hypothesis Ia was not rejected.
2. Hypothesis Ib was rejected.
3. Hypothesis Ic was rejected.

4. Hypothesis IIa was not rejected.
5. Hypothesis IIb was not rejected.
6. Hypothesis IIc was not rejected.

7. Hypothesis IIIa was rejected.
8. Hypothesis IIIb was not rejected.
9. Hypothesis IIIc was rejected.

10. Hypothesis IVa was not rejected.
11. Hypothesis IVb was not rejected.
12. Hypothesis IVc was not rejected.

TABLE 9

MULTIVARIATE ANALYSIS OF VARIANCE
GEFT AND TOLT BY CONCEPTUAL SHIFT (0,1)

SHIFT A

VARIABLE	HYPO SS	ERROR SS	HYPO MS	ERROR MS	F	SIG OF F
GEFT	3.01	907.98	3.01	17.13	.17	.68
TOLT	32.46	286.37	32.46	5.40	6.01	.02

SHIFT B

VARIABLE	HYPO SS	ERROR SS	HYPO MS	ERROR MS	F	SIG OF F
GEFT	.19	910.79	.19	17.18	.32	.92
TOLT	.68	318.15	.68	6.00	.11	.73

SHIFT C

VARIABLE	HYPO SS	ERROR SS	HYPO MS	ERROR MS	F	SIG OF F
GEFT	5.50	905.48	5.50	17.08	.32	.57
TOLT	23.29	295.54	23.29	5.57	4.18	.05

Data in this study supported the hypothesis that there was a significant correlation between conceptual understanding on the post test and on the follow-up test and scores on the TOLT. Data in this study did not support the hypothesis that there was a correlation between conceptual understanding and scores on the GEFT at any time during the study.

The findings of this study also supported the hypothesis that there was a significant difference between the TOLT scores of the students who made conceptual shifts and the students who did not for Shift A and for Shift C. There was no support for the hypothesis that there was a significant difference between the GEFT scores of the students who made conceptual shifts and those who did not.

QUALITATIVE RESULTS

Numbers did not supply all of the important information in this study. An examination of the students' explanations of the burning candle phenomenon and an examination of the nature of their misunderstandings and patterns of shifting was also valuable because it gave some indication of the nature

of the thinking, the conceptual difficulties, and conceptual shifts that the students were making

In their initial explanation of the burning candle phenomenon all but one student expressed an acceptable explanation that the candle went out because of a lack of oxygen in the jar, but 12 out of 55 students (22 percent) did not have any explanation for why the water rose in the jar. Thirty-eight out of 55 (69 percent) had an explanation that was described as naive. The most common explanation was that the candle used up the oxygen causing the water to rise to occupy the space left by the oxygen. The next most common explanation was that the candle was seeking oxygen and "sucked up" the water in an attempt to extract oxygen from the water. See Table 10 on page 79 for a listing of the naive explanations. Five out of 55 (9 percent) of the students wrote partially correct explanations. They described changes in the air pressure inside and outside of the flask but they could not correctly describe the reason for the difference in the inside and outside pressures. Only one student wrote a pretest explanation that was rated as an acceptable one. She was eliminated from the study.

TABLE 10

DESCRIPTION OF NAIVE EXPLANATIONS (CUF=2) USED BY SUBJECTS ON THE PRETEST, POSTTEST AND FOLLOW-UP TEST

Oxygen Model - The candle burns until it uses all of the oxygen in the flask. The water then rises in the flask to take the place of the oxygen that has been used up.

Candle Model - The candle burns until it uses all of the oxygen in the flask. The candle then "sucks" up the water looking for any oxygen that might be in the water.

Smoke Model - The candle burns until it uses up of the oxygen. At the same time the candle is making smoke. The smoke wants to get some oxygen so it "sucks" up the water looking for oxygen.

Carbon Dioxide Model - The candle burns until it uses up the oxygen. The jar is then filled with carbon dioxide which is looking for oxygen. The carbon dioxide "sucks up" the water looking for the oxygen.

Pressure Model - The candle burned until it went out because there was no more oxygen. The high pressure inside of the container made the water rise.

Heat Model - The candle made the the inside of the flask hot. The water gets hot and rises because hot things rise.

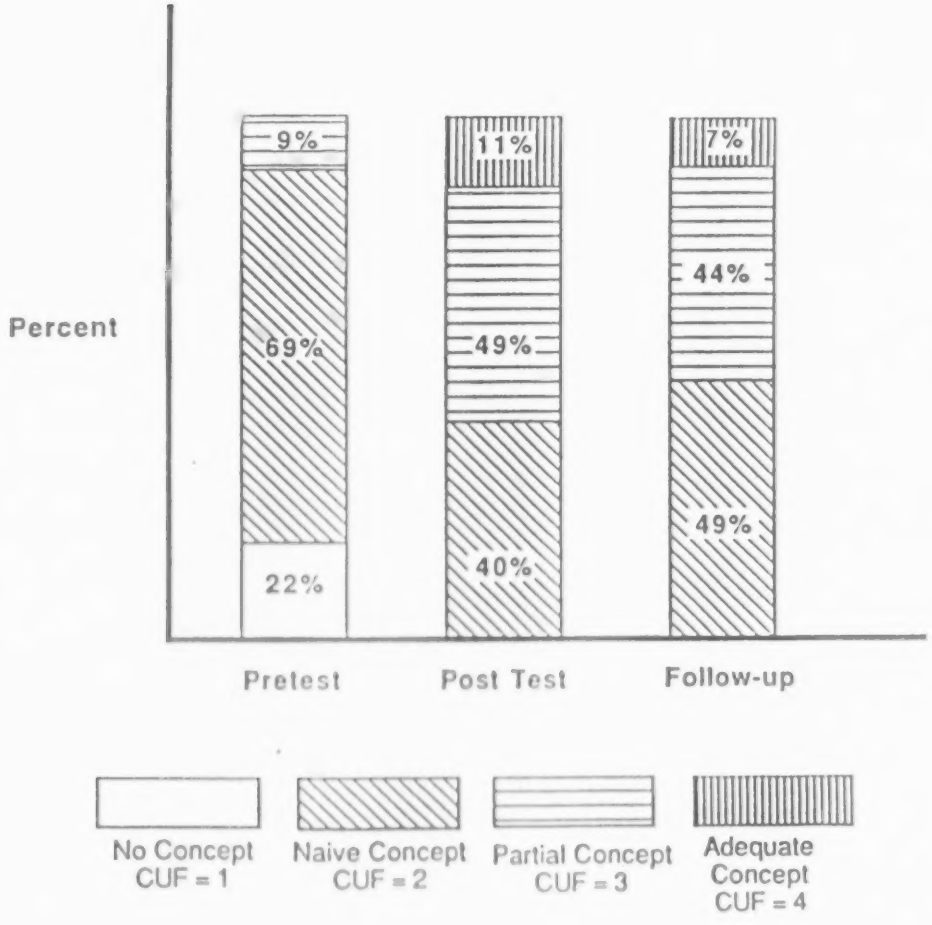
At the end of the three day lesson, the students were tested again to determine their understanding of the burning candle phenomenon. All of the students (n=55) had some type of explanation but 22 (40 percent) still held naive explanations, 27 (49 percent) held partial explanations, and six (11 percent) had an acceptable explanation of the event.

Twenty one days later a follow-up test was given. All of the students wrote an explanation for the event. Twenty-seven (49 percent) of the students wrote naive explanations, 24 (44 percent) gave an explanation that demonstrated partial understanding, and four (7 percent) showed an acceptable understanding of the event (See Table 11 on page 81).

Fifteen of the 55 students (27 percent) did not make a conceptual shift over the three day instructional period while 40 students (73 percent) did make a shift. Thirty-two out of the 55 students (58 percent) made and maintained a conceptual shift from the first day of instruction until the follow-up test 24 days later.

TABLE 11

LEVELS OF UNDERSTANDING AS MEASURED ON THE CUF OF THE BURNING CANDLE PHENOMENON ON THE PRETEST, POSTTEST AND FOLLOW-UP TEST (N=55)



Patterns of understanding levels and their changes were tabulated. See Table 12. Sixty-nine percent of the subjects in the study followed one of these three patterns when explaining the burning candle phenomenon.

TABLE 12

FREQUENCY OF COMMON PATTERNS
OF CONCEPTUAL UNDERSTANDING
AS MEASURED BY THE CUF ON THE
PRETEST, POSTTEST, AND FOLLOW-UP

Number of Students	CUF Score Pattern
18/55	2-3-3
14/55	2-2-2
6/55	2-2-3
38/55	

The most prevalent pattern was the 2-3-3 pattern. Students in this group scored a two on the pretest CUF and a three on the posttest and follow-up CUF. These students made a conceptual shift during the three-day instruction period. They did not gain a completely acceptable understanding of the phenomenon but they did construct a new explanation that was closer to the accepted explanation (See Figure 3 on page 83). They

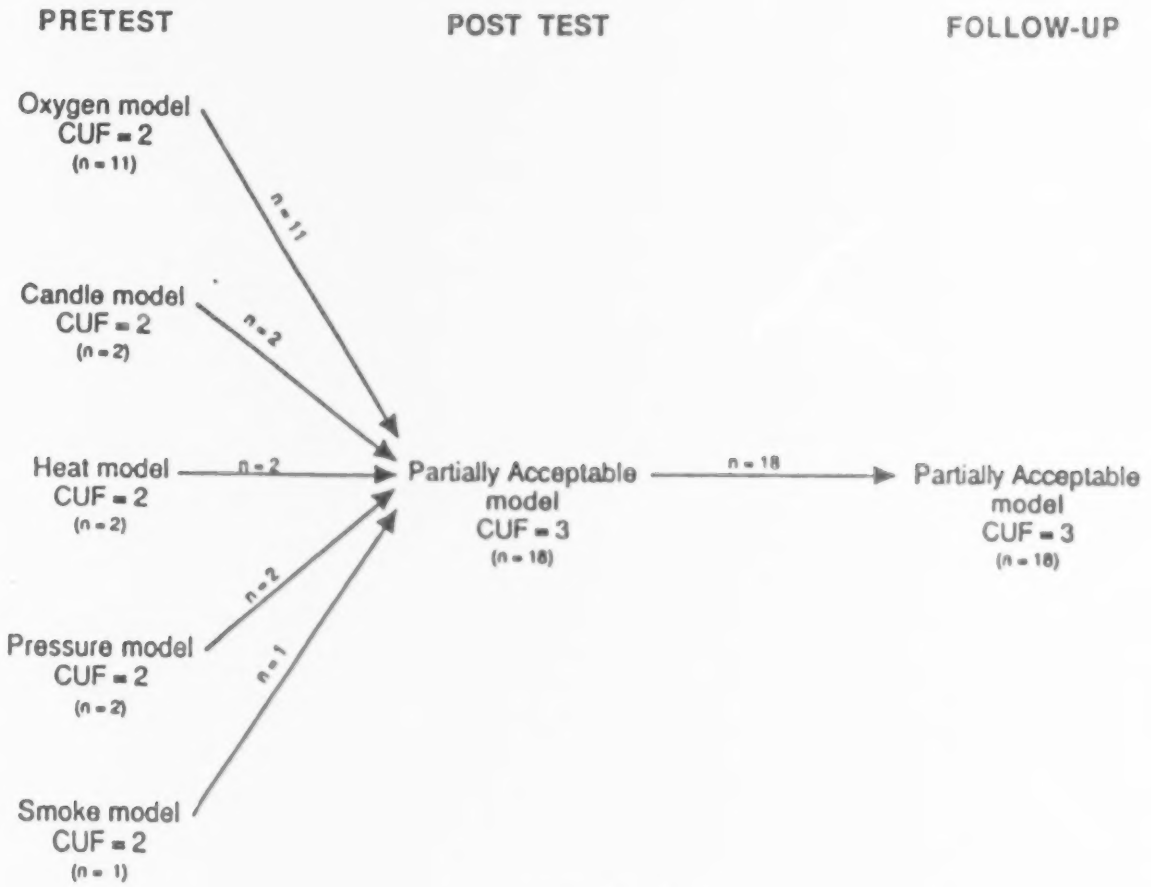


FIGURE 3

CONCEPTUAL UNDERSTANDING MODELS USED BY STUDENTS WHO FOLLOWED A 2-3-2 PATTERN OF UNDERSTANDING ON THE CONCEPTUAL UNDERSTANDING FORM (CUF)

appeared to have incorporated these changes into their cognitive structure because they retained their understanding level (CUF=3) over the 21 days following the instruction.

The second group of students with the 2-2-2 pattern did not make a conceptual shift during the 24 day period of the study (See figure 4 on page 85). The students in this group never increased their understanding of the burning candle phenomenon beyond the naive understanding level but they did not all stay with the same naive understanding model for the duration of the study. It is possible that they were aware of the problems with their initial explanation and were looking for other ideas.

The third group of students with the pattern 2-2-3 began the study with a naive explanation of the burning candle phenomenon. They did not make a conceptual shift immediately following the instruction period but increased their conceptual understanding to a partially acceptable understanding (CUF = 3) during the twenty-one day follow-up period (See Figure 5 on page 86).

Naive explanations (CUF=2) used by students to explain the burning candle phenomenon were characterized as the oxygen model, the candle model,

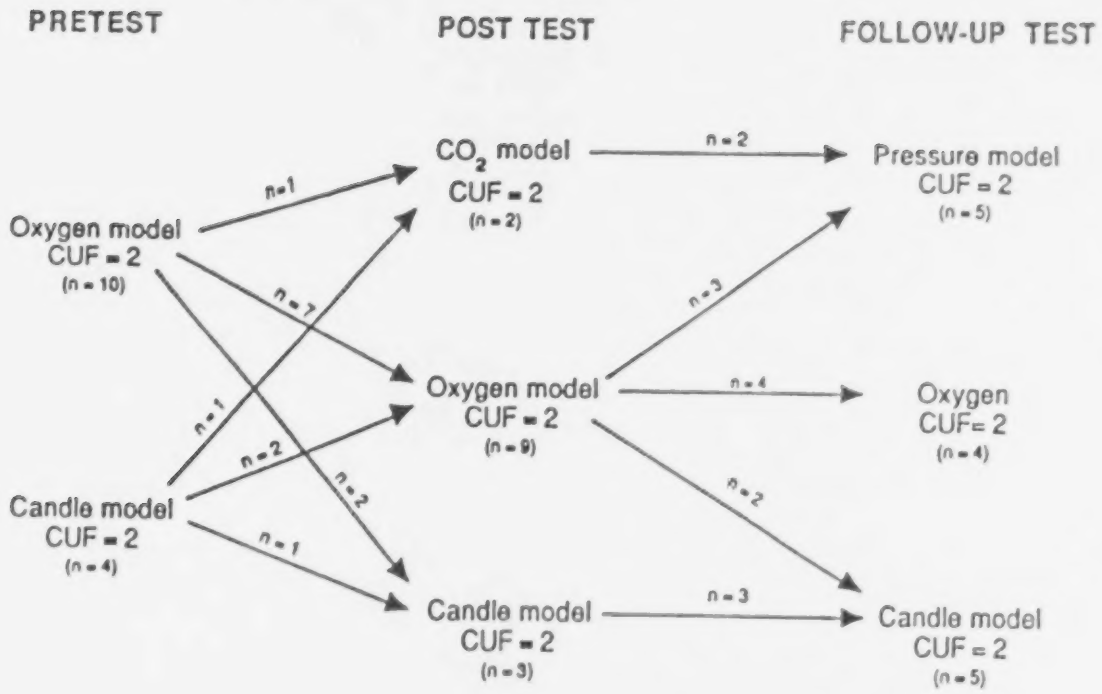


FIGURE 4

CONCEPTUAL UNDERSTANDING MODELS USED BY STUDENTS WHO FOLLOWED A 2-2-2 PATTERN OF UNDERSTANDING ON THE CONCEPTUAL UNDERSTANDING FORM (CUF)

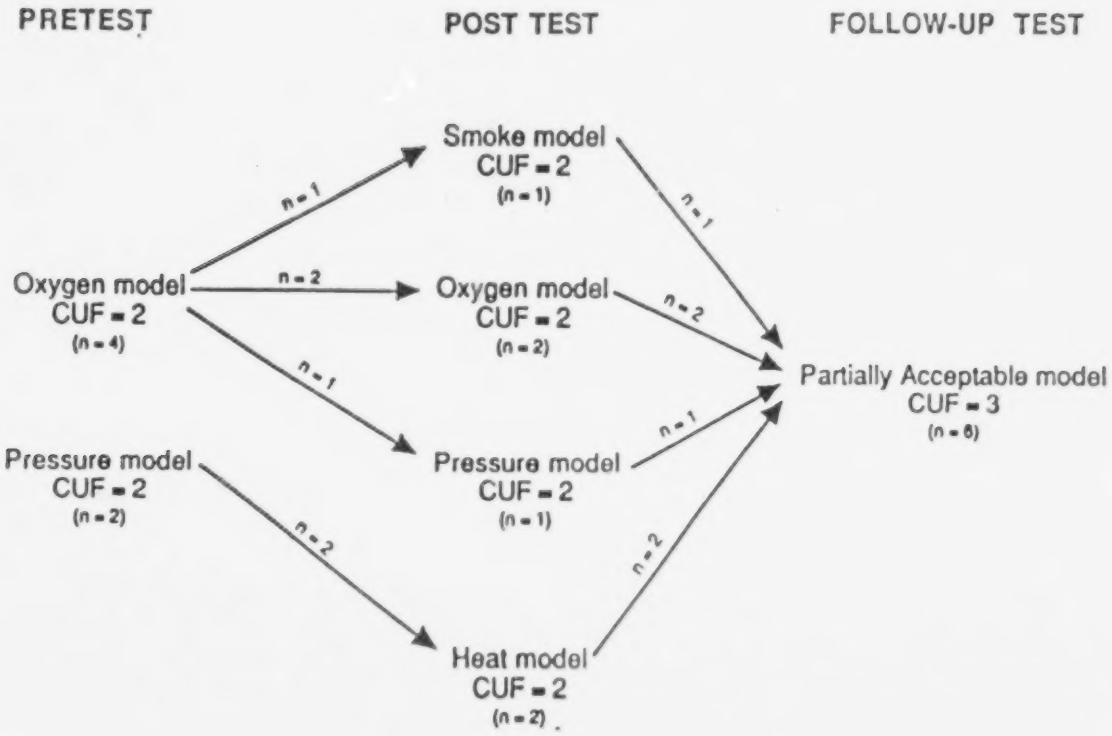


FIGURE 5

CONCEPTUAL UNDERSTANDING MODELS USED BY STUDENTS WHO FOLLOWED A 2-2-3 PATTERN OF UNDERSTANDING ON THE CONCEPTUAL UNDERSTANDING FORM (CUF)

the pressure model, the heat model, the carbon dioxide model and the smoke model. The most common naive model was the oxygen model. It was the most frequent used model on the pretest, posttest and follow-up test. The components of the oxygen model are as follows: (1) The burning candle uses up the oxygen in the jar; (2) The loss of oxygen in the jar creates a vacuum; (3) The water gets pulled up into the jar to replace the empty space left by the oxygen. Twenty-nine out of 38 of the students with naive explanations used the oxygen model at the beginning of the study (Day One). Figure 6 on page 88 shows the pattern of conceptual changes for students who used the oxygen model on the pretest. Eleven out of 29 who began the study with the oxygen model shifted to a partially correct pressure model (CUF=3) on the posttest and 10 out of those 11 stayed with the pressure model on the follow-up test. One subject moved from a partial understanding (CUF=3) to an acceptable understanding (CUF=4) on the follow-up test. Nine out of 29 continued to use the oxygen model after the instruction period but only 3 of those nine subjects continued to use the oxygen model on the follow-up test. One of the nine students shifted to an acceptable understanding (CUF=4) on the follow-up

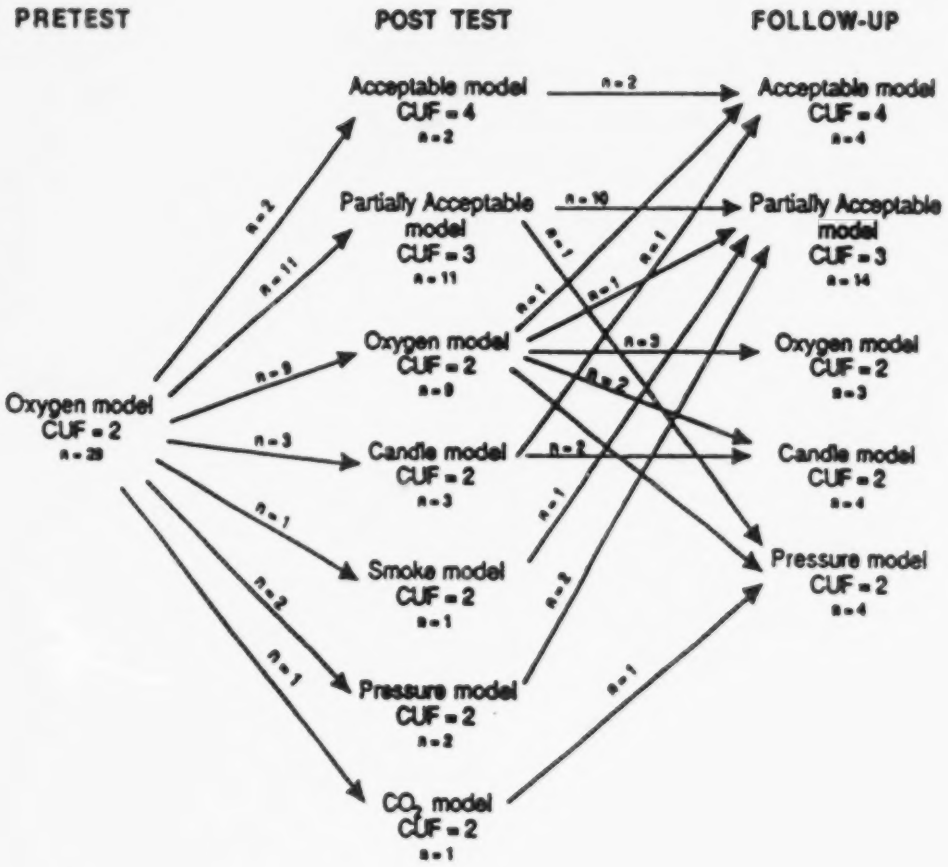


FIGURE 6

CONCEPTUAL UNDERSTANDING MODELS USED ON THE POSTTEST AND FOLLOW-UP TEST BY STUDENTS WHO USED THE OXYGEN MODEL ON THE PRETEST

test, two switched from the oxygen model on the posttest to the candle model (CUF=2) on the follow-up test, two switched to a naive pressure model (CUF=2) and one switched to a partially acceptable pressure model (CUF=3) on the follow-up test.

The belief that the water rises in the jar to replace the lost oxygen was given on the first day by students who did not make a conceptual shift over the course of the study and by those students who did make a conceptual shift. In the group that followed a 2-3-3 pattern, one out of 18 students (60 percent) started the study with the oxygen explanation. For the group that followed a 2-2-2 pattern, ten out of 14 (71 percent) started the study with the oxygen explanation. Only three students kept this concept for the entire study. One student kept the oxygen model for the posttest before shifting to a naive pressure model on the follow-up test. Four students stayed with the oxygen model on the posttest. Two of these then switched to the candle model while two others switched to a naive pressure model. One switched from an oxygen model to the candle model and stayed with it on the follow-up test. One last student moved from the oxygen model to a carbon dioxide model to a naive pressure model. In the 2-2-2 group, the only other naive

explanation besides the oxygen model that was given on the pretest was the candle model. One student stayed with the candle model through the entire study. The others moved from one naive concept to another. In the third largest group which had the pattern, 2-2-3, four out of the six students (67 percent) started the study with the oxygen explanation. Two moved from the oxygen model to a naive pressure model and then to a pressure model that showed partial understanding. One moved from the oxygen model to a smoke model to pressure model that showed partial understanding. The last two students in this group started with a naive pressure model and move to a heat model on the posttest and then shifted to a partially correct pressure model on the follow-up. It is interesting to note that the naive oxygen model appeared in similar frequencies in the naive explanations of students in all three of the common understanding patterns.

On the pretest and on the posttest the candle model was second only to the oxygen model in its frequency of appearance. The candle model uses the lack of oxygen as part of its explanation. It uses the candle as an agent that is causing the water to rise instead of relying on suction or pressure. Eighty-nine percent of the naive explanations on the pretest, and a

large percentage of naive explanations on the posttest and follow-up test were either the oxygen model or the candle model (See Figure 7 on page 93). The naive pressure model gained acceptance on the posttest. After the attention on air pressure and the effects of unequal pressure on the movement of water into and out of flasks some students tried to build on the idea but did not understand enough of it to use it properly.

SUMMARY OF DATA ANALYSIS

Data presented in this chapter supported the hypothesis that logical thinking ability as measured by the TOLT was significantly related to conceptual understanding of the burning candle phenomenon and to the ability to make a conceptual shift. Data presented in this chapter did not support the hypothesis that there was a significant relationship between disembedding ability and conceptual understanding of the burning candle phenomenon. The fact that the average disembedding score as measured by the GEFT of the group of students who made a conceptual shift was consistently higher than the average score of the students who did not indicated that there may be an indirect relationship through the relationship of disembedding ability to logical thinking ability.

An examination of the written explanations given by the students on the pretest, posttest and follow-up CUF forms showed that the oxygen model was the most used naive model in this study. The candle model which is really a variation of the oxygen model was the second most popular model on the pretest and on the posttest. It seemed that overcoming the oxygen model was a major task when teaching the concepts involved in the burning candle phenomenon.

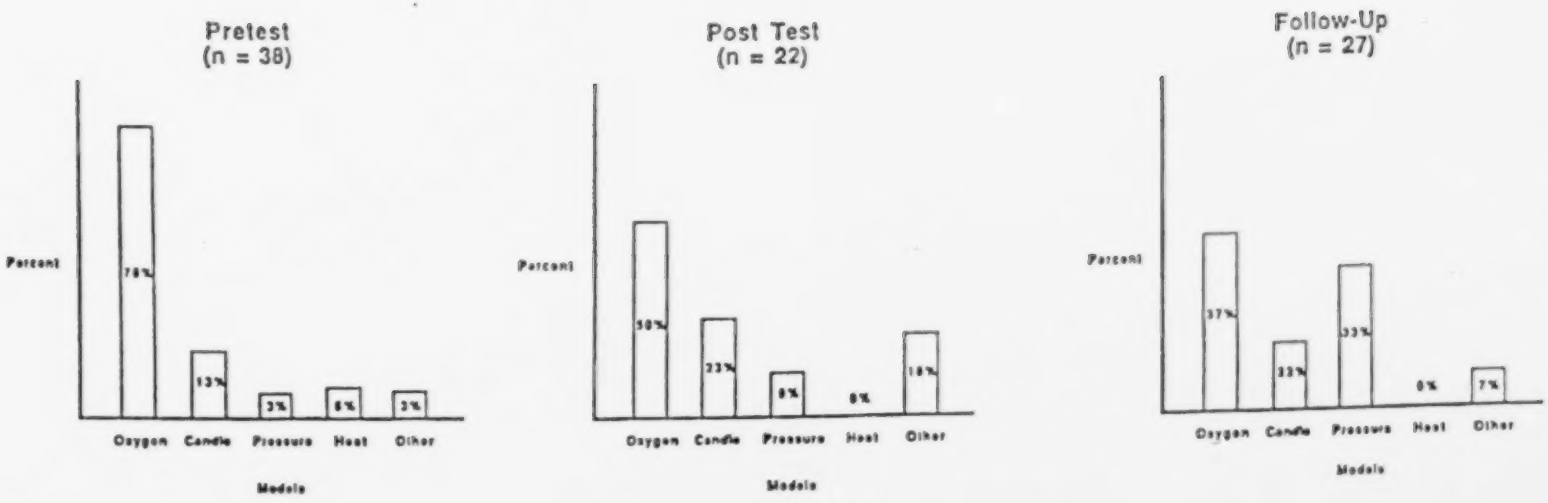


FIGURE 7

DISTRIBUTION OF NAIVE MODELS USED ON THE PRETEST, POSTTEST, AND FOLLOW-UP TEST

CHAPTER V

SUMMARY AND CONCLUSIONS

This chapter is divided into three sections. The first section summarizes the purpose, methods, and results of the study. The second section presents a discussion of the findings and the relationships of these findings to other research studies. The third section presents recommendations for further research, for teachers and for science curriculum.

SUMMARY

The purpose of this study was to determine the relationship of the cognitive variables, logical thinking and disembedding ability, to the learners' ability to make conceptual shifts to more accurate conceptual understandings of a physical phenomenon.

Before the instruction period began, the Test of Logical Thinking (TOLT) and the Group Embedded Figures Test (GEFT) were given to a group of eighth grade students (n=55). The TOLT measured logical thinking ability and the GEFT measured disembedding ability.

The students were then shown the burning candle phenomenon, after which they were given a Conceptual Understanding Form (CUF) pretest on which each student wrote an explanation of the event. Their explanations were rated for their level of conceptual understanding. No explanation was rated as a one, a naive explanation was rated as a two, a partially correct explanation was rated as a three and an adequate explanation was rated as a four. After a three-day lesson on the burning candle phenomenon, the students were given a CUF posttest to measure their understanding of the concepts involved in the burning candle. After a 21-day wait, a CUF follow-up test was given. There was no instruction on the subject of the burning candle during the 21-day follow-up period.

Pearson product-moment coefficients were calculated to test hypotheses I and II. A multivariate analysis of variance (MANOVA) was used to test hypotheses III and IV. The results of the analyses are presented for each hypothesis.

Hypothesis I.

There will be no significant correlation between the level of logical thinking as measured by the TOLT and the level of conceptual understanding measured on the:

a. pretest
b. posttest
c. follow-up test

This hypothesis tested for significant ($p<.05$) correlations between logical thinking ability as measured by the TOLT and the students' level of understanding of the burning candle phenomenon. Pearson-moment correlations were calculated on the relationship between the TOLT and the conceptual understanding form (CUF) scores on the pretest, posttest and follow-up test. Results of the analysis showed significant correlations between the TOLT and the posttest CUF scores ($r=.29$, $p<.05$) and between the TOLT and the follow-up CUF scores ($r=.36$, $p<.01$). There was no significant correlation between the TOLT and the pretest CUF scores ($r=-.13$).

Based on these findings, hypothesis Ia could not be rejected but hypotheses Ib and Ic could be rejected. These results indicated that logical thinking ability as measured by the TOLT had a significant relationship to students' abilities to construct an acceptable

conceptual understanding of the burning candle phenomenon after instruction. The results also indicated that the TOLT had a significant relationship to students' ability to retain an acceptable conceptual understanding during the 21-day period until the follow-up CUF was administered.

Hypothesis II.

There will be no significant correlation between disembedding ability as measured by the GEFT and the level of conceptual understanding measured on the :

a. pretest
b. posttest
c. follow-up test

This hypothesis tested for significant ($p<.05$) correlations between disembedding ability as measured by the GEFT and the students' level of conceptual understanding of the burning candle phenomenon as measured on the CUF. Pearson product-moment correlations were calculated for the relationship between the GEFT scores and the CUF scores on the pretest, posttest, and follow-up test. Results of the analyses showed no significant correlations between the GEFT and the pretest ($r= .11$), the posttest ($r=.15$) or

the follow-up test (r=.16). Based on these findings, hypotheses IIa, IIb, and IIc could not be rejected.

These results indicated that disembedding ability as measured by the GEFT was not significantly related to students' abilities to construct an acceptable conceptual understanding of the burning candle phenomenon.

Hypothesis III.

There will be no significant difference in the mean score on the TOLT for the group of students who make a conceptual shift compared to the mean score of the group of students who do not make a conceptual shift at the following times:

a. pretest to posttest (Shift A)
b. posttest to follow-up test (Shift B)
c. pretest to follow-up test (Shift C).

This hypothesis predicted significant ($p<.05$) differences between the mean score on the TOLT for the group of students who made conceptual shifts and the group of students who did not make conceptual shifts for Shift A, Shift B, and Shift C. Scores of the two groups were analyzed using a multivariate analysis of variance. Results of the analysis indicated a significant difference between the two groups on Shift A ($F=6.01$, $p<.05$) and on Shift C ($F=4.18$, $p<.05$).

There was no significant difference between the two groups on Shift B (F=.11, p<.73) The students who made conceptual shifts at Shift A and Shift C had significantly higher scores on the TOLT than did the students who did not make conceptual shifts at Shift A and Shift C. Based on these findings, hypotheses IIIa and IIIc were rejected. Hypothesis IIIb could not be rejected.

These results indicated that logical thinking ability as measured by the TOLT was related to the ability of a student to make a conceptual shift.

Hypothesis IV

There will be no significant difference in the mean score on the GEFT for the group of students wno make a conceptual shift compared to the mean score for the students who do not make a conceptual shift at the following times:

a. pretest to posttest (Shift A)
b. posttest to follow-up test (Shift B)
c. pretest to follow-up test (Shift C)

This hypothesis predicted significant(p<.05) differences between the mean score on the GEFT for the group of students who made conceptual shifts compared to the average scores for the group of students who did not make conceptual shifts at Shift A, Shift B and Shift C. Scores of the two groups were analyzed using

a multivariate analysis of variance. Results of the analysis showed no significant differences between the two groups at Shift A (F =.17), Shift B (F =.01) or Shift C (F =.32). The students who made conceptual shifts at Shift A, Shift B and Shift C did not have significantly higher scores on the GEFT than did the students who did not make conceptual shift at those times. Based on these findings, hypotheses IVa, IVb and IVc could not be rejected. These results indicated that there was no significant relationship between disembedding ability and the ability to make a conceptual shift.

DISCUSSION

Relationship of Logical Thinking Ability to Conceptual Understanding

Logical thinking ability as measured by the TOLT showed a significant ($p<.05$) correlation to the level of conceptual understanding on the posttest and follow-up test but not on the pretest. The evidence for the hypothesis that there would be a significant correlation came from studies which indicated that logical thinking was significantly related to science achievement (Lawson and Thompson, 1987; Shayer and Wylam, 1981; Chandron, Treagust and Tobin, 1987;

Wylam, 1981; Chandron, Treagust and Tobin, 1987; Mensha, Erickson and Gaskell, 1987, Krajack and Haney, 1987). All of these studies measured the relationship of logical thinking to achievement after instruction. None of them examined the relationship of logical thinking to conceptual understanding before instruction. Only one of the subjects in this study demonstrated an adequate understanding of the burning candle phenomenon on the pretest. Her data were removed from the data set because she had an adequate understanding (CUF=4) of the concept before instruction. One of the delimitations of the study was that any student who exhibited an adequate understanding of the concept (CUF=4) would not be included in this study because the purpose of the study was to examine the presence or absence of conceptual shifts in students who did not initially have an adequate understanding of the burning candle phenomenon. The student did, however, go through the instructional sequence and testing. She continued to write adequate explanations on the posttest and on the follow-up.

Results of the pretest showed that 50 of the 55 subjects (90 percent) had either no conceptual understanding or a naive conceptual understanding of

the event. Five of the 55 subjects (10 percent) had a partial understanding of the burning candle event. The burning candle phenomenon is often misunderstood by teachers and textbook writers. It has even appeared in a recent chemistry lab manual as an event which could be used to prove that the earth's atmosphere consists of 20 percent oxygen (Smoot and Smith, 1987). This lack of correlation between logical thinking ability and pretest conceptual understanding suggests that the subjects in this study may have never been taught this concept or they may have been exposed to incorrect information about this concept.

Relationship of Disembedding Ability to Conceptual Understanding

Disembedding ability as measured by the GEFT did not show a significant correlation with conceptual understanding on the pretest, posttest, or on the follow-up test. It was hypothesized that the GEFT would be significantly related to conceptual understanding because high scores on the GEFT were shown to be directly related to science achievement (Lawson, 1983; Saurenman and Michael, 1980). Other research studies have related disembedding ability to science achievement indirectly through the relationship

of disembedding ability to logical thinking. Lawson (1983) and Linn & Pulos (1983) showed that disembedding ability was related to logical thinking. Stuessy (1989) used path analysis to show that disembedding ability was a significant aptitude needed for logical thinking ability.

If disembedding ability does have an indirect relationship to conceptual understanding through its direct relationship to logical thinking, then any measure of the direct effect of disembedding ability on conceptual understanding was too small to be detected in this study.

Relationship of Logical Thinking Ability to the Ability to Make a Conceptual Shift

It was hypothesized that the group of students who made conceptual shifts would have greater logical thinking abilities than the group of students who did not make conceptual shifts. Results of this study supported this hypothesis. For Shift A there was a significant difference ($F = 6.01$, $p < .05$) and also for Shift C ($F = 4.18$, $p < .05$). The mean TOLT score for the students who made conceptual shifts was higher for all three shifts but the difference in the means for Shift B was not significant. This may be explained by the

fact that there was a 21-day period between the posttest and the follow-up test. During this time there was no instruction or reinforcement for the lesson presented on days one, two, and three. A positive conceptual shift was not expected because there was no further instruction about the concept. Classroom activities during the 21-day period did not pertain to concepts learned during the burning candle activities. The purpose of the 21-day time period between the posttest and the follow-up test was to see how much conceptual understanding was retained. It was assumed that students who maintained a conceptual understanding over the 21 day period did so because they had actively constructed a conceptual understanding as opposed to the students who had memorized the concept presented in the lessons without actively constructing a new concept and incorporating it into their cognitive structure. Eight out of the 55 students in the study actually did show an increase in conceptual understanding over the 21 day time period between the posttest and the follow-up test. It is possible that some type of momentum effect occurred (Kwon & Mayer, 1985). The momentum effect, which has been documented, has shown that learning may continue for up to two weeks after a lesson has been completed.

It is more likely that on the day of the follow-up test, the activity was discussed among the students so that some students who were tested later in the day had discussed explanations with students who had been tested earlier. There was an overall gain in conceptual understanding. The average conceptual understanding score dropped from 2.84 on the posttest to 2.58 on the follow-up test. However, from the pretest to the follow-up 32 out of 55 (58 percent) did make and retain a conceptual shift.

Logical thinking is metacognitive in nature (Nisbett & Ross, 1980; Flavell, 1985). It is an abstract-derivative type of thinking in which the individual monitors his/her own progress. This aspect of logical thinking is very important for thinking and problem solving in the sciences. Nisbett and Ross (1980) describe three keys to logical or scientific thinking. They are: (1) the ability to think about a theory; (2) the ability to encode and represent evidence to be evaluated as a distinct entity; (3) the ability to bracket or set aside acceptance or rejection of a theory. All of these abilities depend on the ability to think about one's cognition. Since logical thinking is necessary for metacognition, it is necessary for thinking in science. Lawson and Thompson

(1987) describe three conditions necessary for overcoming misconceptions in science. They are: (1) the awareness of the scientific concept; (2) the awareness of how evidence supports the concept; (3) awareness of how evidence contradicts the misconceptions. In order to meet these three conditions a student must possess logical thinking skills. These three conditions are variations on Nisbitt and Ross's keys for scientific thinking. The relationship between logical thinking and the ability to make a conceptual shift may be explained by the construct of metacognition.

Logical thinking which consists of the ability to control variables and the ability to do propositional, correlational, probabilistic, and combinatorial reasoning (Lawson, 1978) is metacognitive in nature (Nisbett and Ross, 1980; Flavell, 1985). Flavell (1985) describes metacognition as "thinking about thinking." Kuhn, Amsel and O'Loughlin (1988) describe scientific thinking as the ability to suspend one's own beliefs and to examine one's own thinking about a problem. To make a conceptual shift, a student must reflect on his/her misconceptions and drop them after evaluating the evidence. This requires logical thinking.

Relationship of Disembedding Ability to the Ability to Make a Conceptual Shift

It was hypothesized that the group of students who made conceptual shifts would have greater disembedding ability than the group of students who did not make conceptual shifts. Results of this study did not support this hypothesis. While there was no significant difference ($p<.05$) between the GEFT scores for the two groups on Shift A, Shift B, and Shift C, the average GEFT score for group of students who did make a conceptual shift was higher for all three shifts. As has already been discussed earlier in this chapter, if disembedding ability was indirectly related to the ability to make a conceptual shift through its relationship to logical thinking ability, its effect on the ability to make a conceptual shift was not significant enough to be detected.

Qualitative Results

An examination of the student explanations of the burning candle phenomenon and the their patterns of changes over the course of this study confirmed research that has pointed out that misconceptions are difficult to replace (Targan, 1987; Hewson, 1986; Hashweh, 1988). While 40 out of 55 students (73

percent) made a conceptual shift over the three-day instructional period, only 32 out of 55 (58 percent) retained the shift until the follow-up test on day 24.

On day one of the study, 12 (21 percent) of the students wrote no explanation for the event. Another 37 of the students (68 percent) had a naive misconception of the event. The most common misconception was the oxygen model. This model stated that after the candle used up all of the oxygen in the jar, the water rose to take up the space formerly occupied by the oxygen. A variation of this model was the candle model which stated that after the candle used up the oxygen, the candle "sucked up" the water in an attempt to extract oxygen from the water. These two models accounted for 89 percent of the naive explanations on the pretest. This information confirms findings (Rogan, 1988) that there are usually one or two naive models of a physical phenomenon that appear more frequently than others.

Misconceptions are difficult to dislodge and misconceptions which form around concrete objects and observations are the most difficult to correct (Clough and Driver, 1986). An examination of the commonly held misconceptions in this study were in agreement with these findings. The rising of the water in the jar was perceived to be caused by visible agents, the smoke,

and the candle. Heat which cannot be seen but can be felt was also identified as an agent. The lack of oxygen can also be perceived as a "very real" agent by eighth grade students. From an early age, students have learned about oxygen and its importance to living things and to burning. They have been exposed to the concept that the air is composed of 20 percent oxygen and that candles "use up" oxygen when they burn. Most of them are also familiar with the concept that air takes up space.

Eighteen of the 55 students (33 percent) in the study made a shift from a naive misunderstanding of the burning candle phenomenon to a partial understanding. They maintained this level of understanding over the 21-day follow-up period. Students who had an acceptable explanation of the phenomenon on day 3, maintained this level on day 21. These results showed that misconceptions could be replaced in a short period of time and that the newly constructed explanation could be retained.

CONCLUSIONS

1. There is a significant correlation between logical thinking ability and conceptual understanding .

2. There is no significant correlation between disembedding ability and conceptual understanding.

3. There is a significant relationship between logical thinking ability and the ability to make a conceptual shift.

4. There is no significant relationship between disembedding ability and the ability to make a conceptual shift.

5. Students construct explanations for phenomena formally or informally.

6. When students make conceptual shifts they do not always shift to a more adequate conceptual understanding of an event.

7. It is difficult to change students' explanations of physical phenomena.

RECOMMENDATIONS

For Curriculum

Developers of curriculum, like classroom teachers, should become more aware of the misconceptions held by students. Curriculum should acknowledge the historical misconceptions which have been common in science history. It has been shown that "common sense" misconceptions held by students are similar to misconceptions held be scientists in earlier times (Rogan, 1988). Acknowledgement of these misconceptions may make students aware of their own misconceptions and it may help them to see that holding misconceptions is a universal problem and not unusual (Hewson and Hewson, 1983).

Curriculum developers should be aware that some concepts are much more difficult to learn than others. Careful decisions must be made as to the grade level placement of concepts. If they are presented too early in the curriculum, students may not possess the logical thinking skills necessary for evaluating the evidence supporting the concept. If the concept is placed in the curriculum too late, students may construct unacceptable concepts which may be very difficult to dislodge.

When curriculum is planned for early adolescents who are in middle school, the planners must take into consideration the early adolescents' logical thinking abilities. The subjects in this study, who were middle school students, had an average score of 2.85 out of 10 on the Test of Logical Thinking. Their logical thinking abilities were not yet well-developed. We do know that middle school children are beginning to develop their logical thinking skills and to think in a metacognitive manner (Flavell, 1985; Latch and Linn, 1980; Lawson, Lawson and Lawson, 1984). We know that they will sometimes use logical thinking skills and sometimes they will not. Curriculum should be designed in such a way so it pushes them to use their newly developing logical thinking skills but it should not be so abstract as to frustrate students to a point that they will not be willing to work in science.

For Teachers

Data gathered in this study confirm past research that describes the conceptual understanding topography in a classroom. Teachers need to be reminded that students are not sitting in the classroom with blank minds. They have already constructed explanations for many of the events they see in the science classroom

even if they have had no formal instruction in the particular area being taught. We also know that they will construct a concept which may not be accurate but which makes sense to them if they do not understand the concept as taught in the classroom. We have seen that they will search for new explanations when they become aware that their explanations are inadequate but that they do not always replace their naive or inadequate ideas with more adequate ones.

Teachers should gather data in their own classrooms. They should become familiar with the misconceptions that their students bring to the classroom. Teachers should acknowledge these misconceptions in their teaching and pay particular attention to evidence that conflicts with these misconceptions. Research has shown that the acknowledgement of misconceptions can lead to better understanding of acceptable conceptual understanding (Cole and Raven, 1969; Hewson and Hewson, 1983; Stavy and Berkovitz, 1980).

For Logical Thinking Skills

Logical thinking skills are not well developed in middle school students. Research has shown that these skills develop over time and that during early

adolescence there are large gains in the ability to think logically (Flavell, 1985). It has also been shown that during the middle school years learners may or may not use their newly developing logical thinking skills according to the nature and difficulty of the subject matter presented. Attention should be drawn to specific logical thinking skills and to the specific instances when it is appropriate to use them.

The identification of logical thinking skills and the application of these skills to science learning will aid students who are ready to think logically. These skills should be presented and used but it should not be assumed that all students will be successful at using them. Exposure to the teaching of logical thinking may promote the use of these skills at some later time for those students who are not yet ready to use them when they are presented in the curriculum.

If disembedding ability influences logical thinking skills, then expose learners to situations where they must pick the salient information out of the surrounding irrelevant field. Disembedding ability is described as a cognitive style or preference which does not change over time. Individuals may prefer to analyze the parts of the whole (field-independent) or they may prefer to look at the whole field without

identifying the parts (field-dependent), but individuals may be able to overcome their preference if they see a reason to do so. If disembedding ability affects logical thinking, helping field-dependent students to overcome their preferred mode of thinking may improve their logical thinking capabilities. Since there is a significant relationship between logical thinking skills and the ability to make a conceptual shift, improving logical thinking skills should increase students' abilities to make conceptual shifts.

For the Learner

The learners in this study were eighth grade students. Most had been exposed to formal science education for eight or nine years and to informal science instruction through books, television, and museums for 10 to 12 years. The explanations they wrote on the CUF forms showed that most of them tried to construct a meaningful explanation for a science phenomenon. Many of them did not have well-developed logical thinking skills. This did not stop the students from trying to understand the event. It did prevent many of them from properly evaluating the evidence they

had gathered so they could construct an acceptable explanation.

Learners do construct explanations. The emphasis of science education should be to help the learner recognize and apply the appropriate skills needed to construct new concepts and to restructure old ones.

For Further Research

Knowledge in the area of conceptual shifts is in the hypothesis formation and model building stage (Hashweh, 1988). More descriptive information needs to be collected. In addition to gathering quantitative data on the skills and characteristics of learners who make conceptual shifts, more qualitative data need to be documented. There should be more studies using the clinical interview format to document and analyze learners understandings of concepts and the procedural knowledge learners' use to make conceptual shifts. Longitudinal studies should be done to determine the conceptual understanding and procedural knowledge changes that occur as learners mature.

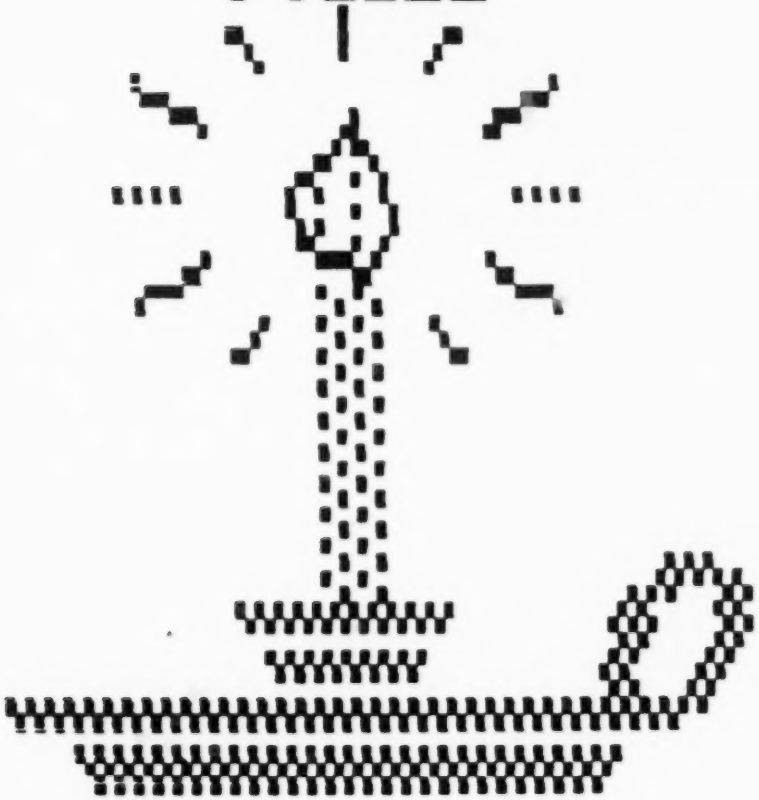
Hashweh (1988) has suggested that after the clinical interview information has been gathered, the result should be confirmed using structured tests on large numbers of learners in different age groups.

After this information is gathered, then hypotheses can be constructed to explain mechanisms of conceptual shifts and the construction of conceptual understandings.

APPENDIX A

STUDENT WORKSHEETS

THE BURNING CANDLE PUZZLE



NAME----------

GROUP-----

THE BURNING CANDLE

I. MATERIALS: flat container, candles, supply of water, matches, 2 rubber bands

II. DIRECTIONS:

a. Light the candle. Drip some wax on the bottom of the pan and use the wax to anchor the candle to the bottom of the pan. Extinguish the candle.

b. Pour water into the container until it is about three-fourths full.

c. Light the candle.

d. Place the cylindrical container over the candle. Quickly move the cylinder down over the burning candle until the open end of the cylinder is at least beneath the surface of the water. The cylinder may rest of the bottom of the container but do not hold it down too tightly.

e. Practice several times so you can make the movement quickly.

f. When you feel you have practiced enough, take a paper towel and wipe all moisture from the jar. Turn the jar upside down and move it back and forth. You must do this to drive out the smoke and candle-combustion products; the drying is insurance against cracking.

g. You are now ready to collect data. Place the cylinder over the candle and observe what happens. The entire chain of events happens so rapidly that you will probably need to do the experiment three or four times to be sure your observations are precise. Be sure to remove the smoke and candle-combustion products from the container after each observation.

III. OBSERVATIONS

What did you observe when you placed the container over the burning candle? PLEASE LIST THEM AND NUMBER THEM.

1._____

2._____

_____

_____

_____

IV. MORE OBSERVATIONS

Observe the Mouse and Candle video.

1. What happened?

2. This video may contradict some ideas you had about the candle in the container. What questions or problems does this video bring up?

V. TRY SOME VARIATIONS ON YOUR FIRST EXPERIMENT.

a. Try using different numbers of candles. Measure the time it takes the candles to go out. Measure the height of the water in the container when you use different numbers of candles.

b. Take 4 candles and put a rubberband around them. Make sure they will stand up in your pan.

c. Light one of the candles. Place the jar over the container. Measure the height of the water in the container after the candle goes out.

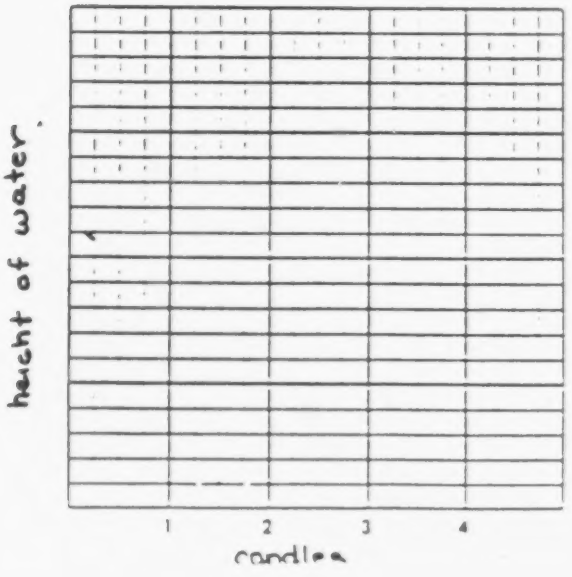
d. Clean the container and remove the combustion products. Light two candles and put the jar over the candles. Measure the height of the water in the container after the candle goes out.

e. Repeat this procedure with three and then with four candles.

Data Table:

Number of candles	Height of water in jar (cm)
1	
2	
3	
4	

Graph:



What is the relationship between the number of candles and the height of the water in the jar?

This experiment may contradict your explanation of the candle and the rising water event. Explain how it does or does not contradict your explanation.

VI . CONCEPT INVENTION

VII . MORE EXPERIMENTS

NUMBER ONE

A. Obtain three test tubes and three small balloons.
B. Fasten a balloon over each of the test tubes.

c. Place the first balloon in a container of hot water.

d. Place the second balloon in a container of water at room temperature.

e. Place the third balloon in a container of hot water.

f. Observe the three test tubes. Draw your observations below.

Questions. Explain your observations of the test tubes with the balloons.

Tube #1_____

_____

Tube #2 _____

_____

Tube #3_____

NUMBER TWO

A. Take an empty soda can. Place a about 5 ml of water in it and place it on a hot plate until you see the steam coming out of the hole in the top for 1 minute. Use your beaker tongs. Quickly pick up the can . Turn it over and place it, hole side down into a container of cold water.

What happens?_____

_____

Can you explain what happens? Use the terms air pressure, inside pressure and outside pressure.

_____

_____

_____

NUMBER THREE

Observe the demonstration with the egg and the flask.

a. What do you observe?_____

b. Explain what happened. Use the terms air pressure, inside pressure and outside pressure.

NUMBER FOUR

Obtain a syringe and some rubber tubing. Use the container which held water in your burning candle experiment. Nearly fill the container with water and place the open end of the empty cylinder under the surface of the water. Hold the cylinder in this position. Use your syringe and tubing to fill the contain with water.

How did you fill the container with water? Why did it work?

APPENDIX B

TEST OF LOGICAL THINKING
(TOLT)
AND THE ANSWER SHEETS

TOLT

Instruction Sheet

Ten problems are presented. Items (1) - (8) will pose a question. Record the answer you have chosen on the sheet you have been given. Items one through eight will also require you to choose from five reasons to explain your answer. Mark the letter on the sheet that corresponds to the reason you select.

Items nine and ten will be answered on the test sheet in the blank spaces provided.

Orange Juice (Item 1)

1. Four large oranges are squeezed to make six glasses of juice. How much juice can be made from six oranges?

   A. 7 glasses

   B. 8 glasses

   C. 9 glasses

   D. 10 glasses

   E. other

2. Reason

   A. The number of glasses compared to the number of oranges will always be in ratio 3 to 2.

   B. With more oranges, the difference will be less.

   C. The difference in the numbers will always be two.

   D. With four oranges the difference was 2. With six oranges the difference would be two more.

   E. There is no way of predicting.

Orange Juice (Item 2)

3. Given the information in Item 1, how many oranges are needed to make 13 glasses of juice?

   A. 6 1/2 oranges

   B. 8 2/3 oranges

   C. 9 oranges

   D. 11 oranges

   E. other

4. Reason

   A. The number of oranges compared to the number of glasses will always be in the ratio 2 to 3.

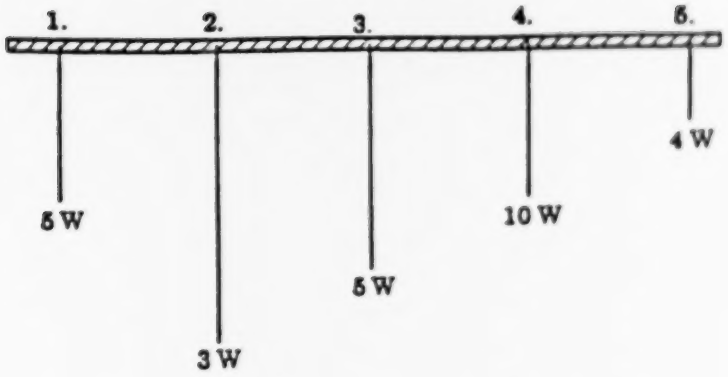
   B. If there are seven more glasses, then five more oranges are needed.

   C. The difference in the numbers will always be two.

   D. The number of oranges will be half the number of glasses.

   E. There is no way of predicting the number of oranges.

The Pendulum's Length (Item 3)



5. Suppose you wanted to do an experiment to find out if changing the length of a pendulum changed the amount of time it takes to swing back and forth. Which pendulums would you use for the experiment?

   A. 1 and 4

   B. 2 and 4

   C. 1 and 3

   D. 2 and 5

   E. all

6. Reason

   A. The longest pendulum should be tested against the shortest pendulum.

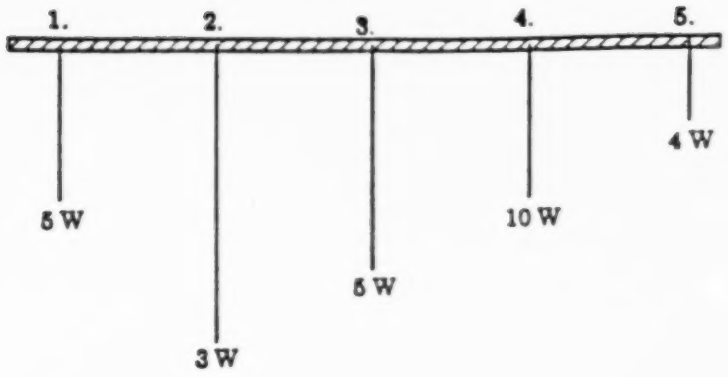
   B. All pendulums need to be tested against one another.

   C. As the length is increased the number of washers should be decreased.

   D. The pendulums should be the same length but the number of washers should be different.

   E. The pendulums should be different lengths but the number of washers should be the same.

The Pendulum's Length (Item 8)



7. Suppose you wanted to do an experiment to find out if changing the weight on the end of the string changed the amount of the time the pendulum takes to swing back and forth.

Which pendulums would you use for the experiment?

A. 1 and 4

B. 2 and 4

C. 1 and 3

D. 2 and 5

E. all

8. Reason

A. The heaviest weight should be compared to the lightest weight.

B. All pendulums need to be tested against one another.

C. As the number of washers is increased the pendulum should be shortened.

D. The number of washers should be different but the pendulums should be the same length.

E. The number of washers should be the same but the pendulums should be different lengths.

The Vegetable Seeds (Item 3)

9. A gardener bought a package containing 3 squash seeds and 3 bean seeds. If just one seed is selected from the package what are the chances that it is a bean seed?

   A. 1 out of 2

   B. 1 out of 3

   C. 1 out of 4

   D. 1 out of 6

   E. 4 out of 6

10. Reason

   A. Four selections are needed because the three squash seeds could have been chosen in a row.

   B. There are six seeds from which one bean seed must be chosen.

   C. One bean seed needs to be selected from a total of three.

   D. One half of the seeds are bean seeds.

   E. In addition to a bean seed, three squash seeds could be selected from a total of six.

The Flower Seeds (Item 6)

A gardener bought a package of 21 mixed seeds. The package contents listed:

3 short red flowers

4 short yellow flowers

5 short orange flowers

4 tall red flowers

2 tall yellow flowers

3 tall orange flowers

11. If just one seed is planted, what are the chances that the plant that grows will have red flowers?

A. 1 out of 2

B. 2 out of 3

C. 1 out of 7

D. 1 out of 21

E. other

12. Reason

A. One seed has to be chosen from among those that grow red, yellow or orange flowers.

B. 1/4 of the short and 4/9 of the talls are red.

C. It does not matter whether a tall or a short is picked. One red seed needs to be picked from a total of seven red seeds.

D. One red seed must be selected from a total of 21 seeds.

E. Seven of the twenty one seeds will produce red flowers.

The Mice (Item 7)

13. The mice shown represent a sample of mice captured from a part of a field. Are fat mice likely to have black tails and thin tails and thin mice more likely to have white tails?

    A. Yes

    B. No

14. Reason

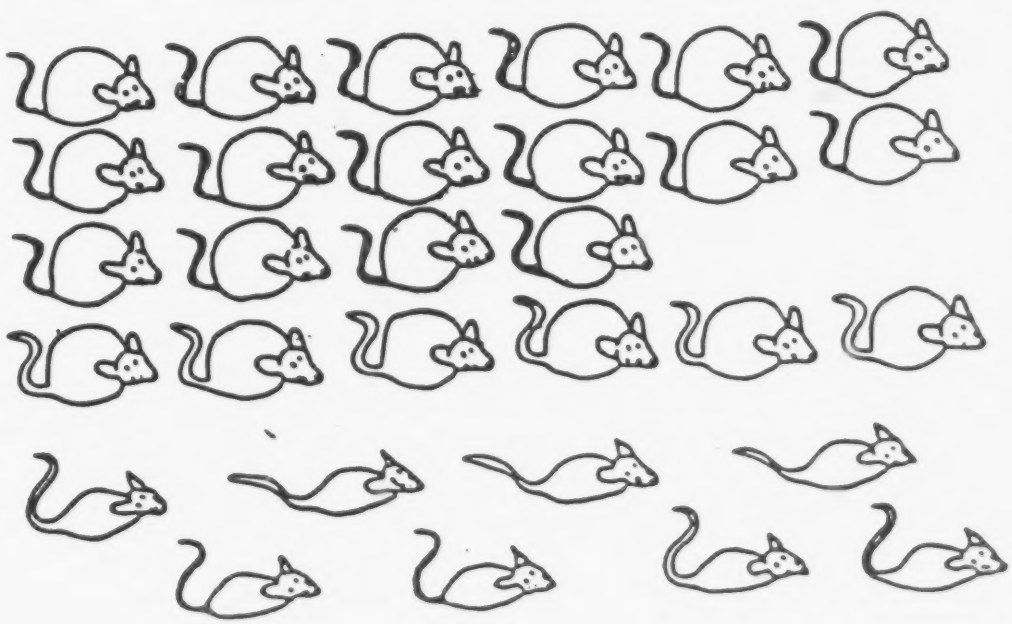
    A. 8/11 of the fat mice have black tails and 3/4 of the thin mice have white tails.

    B. Some of the fat mice have white tails and some of the thin mice have white tails.

    C. 18 mice out of thirty have black tails and 12 have white tails.

    D. Not all of the fat mice have black tails and not all of the thin mice have white tails.

    E. 6/12 of the white tailed mice are fat.



The Fish (Item 8)

15. Are fat fish more likely to have broad stripes than thin fish?

A. Yes

B. No

16. Reason

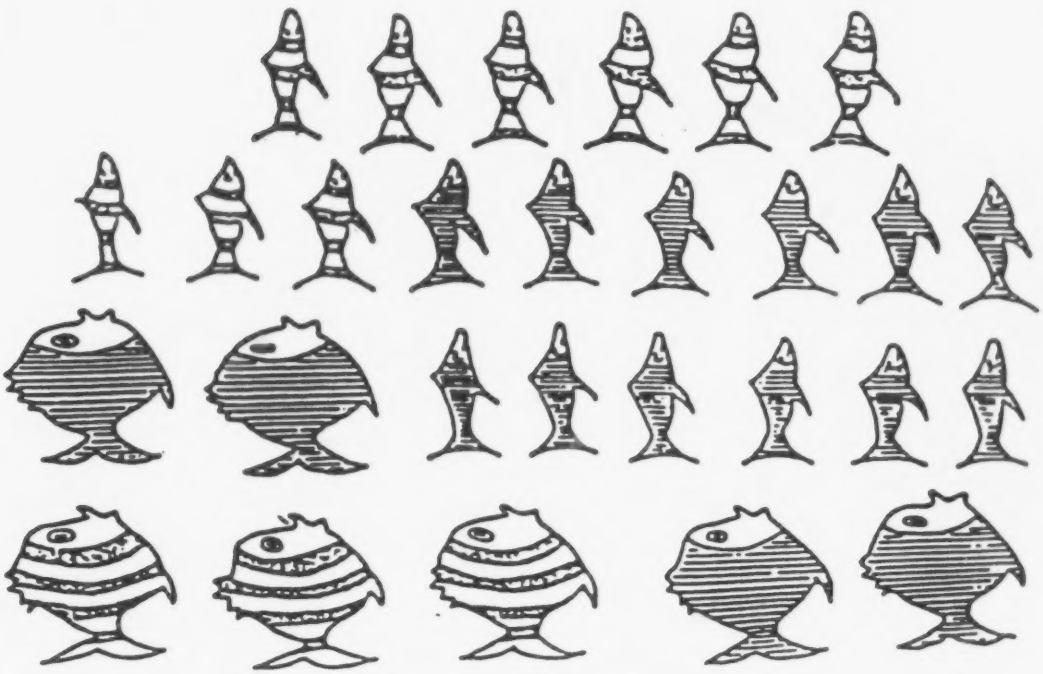
A. Some fat fish have broad stripes and some have narrow stripes.

B. 3/7 of the fat fish have broad stripes.

C. 12/28 are broad striped and 16/28 are narrow striped.

D. 3/7 of the fat fish have broad stripes and 9/21 of the thin fish have broad stripes.

E. Some fish with broad stripes are thin and some are fat.



TOLT ANSWER SHEETS I.D. NO

In this test, ten items are presented. You will find items (1) through (8) in the test booklet. You will mark your answers to those items by blackening in the spaces provided below. Items (9) and (10) are attached to this answer sheet.

Item 1

1. (A) (B) (C) (D) (E)
2. (A) (B) (C) (D) (E)

Item 2

3. (A) (B) (C) (D) (E)
4. (A) (B) (C) (D) (E)

Item 3

5. (A) (B) (C) (D) (E)
6. (A) (B) (C) (D) (E)

Item 4

7. (A) (B) (C) (D) (E)
8. (A) (B) (C) (D) (E)

Item 5

9. (A) (B) (C) (D) (E)
10. (A) (B) (C) (D) (E)

Item 6

11. (A) (B) (C) (D) (E)
12. (A) (B) (C) (D) (E)

Item 7

13. (A) (B)
14. (A) (B) (C) (D) (E)

Item 8

15. (A) (B)
16. (A) (B) (C) (D) (E)

Answer Sheet, p. 2 I.D. NO._____

Instructions for Items (9) and (10)

On Items (9) and (10) you will answer directly in the spaces provided. Item (9) appears below, and Item (10) is on the next page.

The Student Council (Item 9)

Three students from each of grades 10, 11, and 12 were elected to the student council. A three member committee is to be formed with one person from each grade. All possible combinations must be considered before a decision can be made. Two possible combinations are Tom, Jerry and Dan (TJD) and Sally, Anne and Martha (SAM). List all other possible combinations in the spaces provided. More spaces are provided than you will need.

STUDENT COUNCIL

Grade 10	Grade 11	Grade 12
Tom (T)	Jerry (J)	Dan (D)
Sally (S)	Anne (A)	Martha (M)
Bill (B)	Connie (C)	Gwen (G)

TJD	SAM	____	____
____	____	____	____
____	____	____	____
____	____	____	____
____	____	____	____
____	____	____	____
____	____	____	____
____	____	____	____
____	____	____	____
____	____	____	____

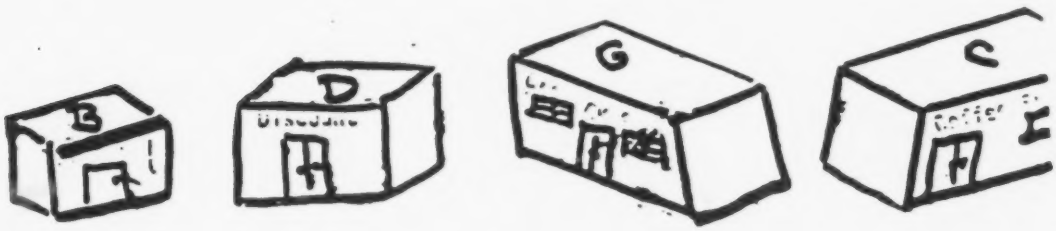
answer sheet, page 1

The Shopping Center

In a new shopping center, 4 stores are going to be placed on the ground floor. A BAKERY SHOP (B), a DISCOUNT STORE (D), a GROCERY STORE (G), and a COFFEE SHOP (C) want to locate there.

One possible way the stores could be arranged in the four locations is BDGC. This means the BAKERY SHOP is first, the DISCOUNT STORE next, then the GROCERY STORE and the COFFEE SHOP last.

LIST ALL THE OTHER POSSIBLE WAYS THAT THE STORES CAN BE LINED UP IN THE FOUR LOCATIONS. You are provided with more spaces than you will need.



BDGC

APPENDIX C

GROUP EMBEDDED FIGURES TEST (GEFT) SAMPLE QUESTIONS AND ANSWERS

GROUP EMBEDDED FIGURES TEST

By Philip K. Oltman, Evelyn Raskin, & Herman A. Witkin

Name _____ Sex _____

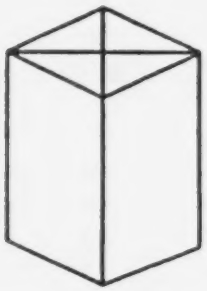
Today's date _____ Birth date _____

INSTRUCTIONS This is a test of your ability to find a simple form whe it is hidden within a complex pattern.

Here is a simple form which we have labeled "X"

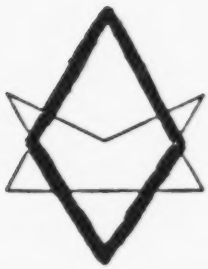
X

This simple form, named "X", is hidden within the more complex figure below:



Try to find the simple form in the complex figure and trace it *in pencil* directly over the lines of the complex figure. It is the SAME SIZE, in the SAME PROPORTIONS, and FACES IN THE SAME DIRECTION within the complex figure as when it appeared alone.

When you finish, turn the page to check your solution.



In the following pages, problems like the ones above will appear. On each page you will see a complex figure, and under it will be a letter corresponding to the simple form which is hidden in it. For each problem look at the BACK COVER of this booklet to see which simple form to find. Then try to trace it in pencil over the lines of the complex figure. Note these points:

1. Look back at the simple forms as often as necessary.

2. ERASE ALL MISTAKES.

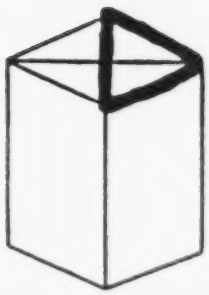
3. Do the problems in order. Don't skip a problem unless you are absolutely "stuck" on it.

4. Trace ONLY ONE SIMPLE FORM IN EACH PROBLEM. You may see more than one, but just trace one of them.

5. The simple form is always present in the complex figure in the SAME SIZE, the SAME PROPORTIONS, and FACING IN THE SAME DIRECTION as it appears on the back cover of this booklet.

Do not turn the page until the signal is given

3



Note that the top right-hand triangle is the correct one: the top left-hand triangle is similar, but faces in the opposite direction and is therefore *not* correct.

Now try another practice problem. Find and trace the simple form named "Y" in the complex figure below it:

Y

Look at the next page to check your solution.

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APPENDIX D

EXPLANATION OF THE BURNING CANDLE EVENT

DESCRIPTION OF THE BURNING CANDLE EVENT

The burning candle phenomenon is one that shows up in many science classes in elementary and junior high school. A burning candle is placed in a small shallow pan filled with water. A jar or flask is placed over the candle. After a few seconds the candle flame goes out and the water rises in the container. Two questions are usually asked. The first is: Why did the candle go out?" The explanation that is given is that the candle uses up the oxygen in the container. When it no longer gets enough oxygen to support combustion the candle goes out. The other question is: " Why does the water rise in the flask?" A common answer is that after the oxygen is used up by the candle there is a space left in the container. The water rises to take the place of the missing oxygen. The burning candle event with the explanation that has just been given has appeared in a high school chemistry lab manual as a proof that air is made up of 20% oxygen (Smoot and Smith, 1987).

A closer investigation of this event shows that the water does not rise to replace the missing oxygen. The chemical equation for this reaction is:

$$2\ C_{36}H_{74}(s) + 109\ O_2(g) \longrightarrow 72\ CO_2(g) + 74\ H_2O(g)$$

An examination of the balanced reaction shows that for every 109 moles of oxygen gas used to burn the candle wax there are 72 moles of carbon dioxide gas and 74 moles of water vapor produced. At the same temperature and pressure one mole of any gas occupies the same volume as one mole of any other gas. In the case of the burning candle for every 109 moles of gas used up there are 146 moles of gas produced. It is clear that after the candle burns there is more gas in the container than there was before the candle was burned.

Expansion of the heated gases inside the flask is the key to the burning candle phenomenon. If you burn two candles instead of one, the water will rise higher in the flask. It will rise even higher when three, four or even five candles are burned at the same time. This indicates that the amount of heat generated in the flask is important. A careful examination of the flask and candle shows that when the candle is going out

there are large bubbles that appear at the lip of the flask. The accepted explanation for this event is that as the candle burns in the flask the heat of combustion warms the gases in the container. As the gases become warmer they expand, increasing the pressure inside the container. As the pressure builds the gases escape from the bottom of the flask. When the candle goes out, the gases remaining in the flask cool off and contract. This lowers the pressure of the gases inside the container. The pressure of air outside of the flask then pushes the water up into the flask until the pressure of the air outside of the flask is equal to the pressure of the gases inside of the flask.

Another variable which must be considered in the burning candle event is the solubility of carbon dioxide in water. Some of the carbon dioxide produced while the candle is burning dissolves in the water at the bottom of the flask. As the carbon dioxide is removed from the jar and is dissolved in the water there is a decrease in the pressure inside of the flask.

APPENDIX E

CONCEPTUAL UNDERSTANDING FORM (CUF)

Name _____

I. D. Number _____

Day Three

1. Explain why the candle went out.

2. Explain why the water rose in the container. Be as complete as possible.

3. Where did your explanation come from?

APPENDIX F

STUDENT PERMISSION LETTER

October 3, 1989

Dear Parents,

I would like to tell you about myself. I am a teacher at Worthington High School and a doctoral student at the Ohio State University. I taught at Perry Middle School for fourteen years before moving to the high school and I am very much interested in learning more about how middle school children learn science concepts.

I would like to have the students on Team 8-2 participate in a research project. The purpose of this study is to describe the changes which take place when a student learns a new science concept.

This study will take four class periods. The first period will be used to administer tests which will assess logical thinking skills and the ability to locate a previously seen simple figure within a larger complex figure. The next three classes will be used to teach a science concept through laboratory experiences. The concept and teaching method is in harmony with the graded course of study and methods already in use in the eighth grade science curriculum.

Data from written student responses concerning the concepts taught and from their test scores on the logical thinking test and on the test for recognizing hidden figures will be used to compare characteristics of students who learn concepts in different ways. Individual results will be coded and used to compile group statistics. No results will be entered into the students' permanent file.

When the work is completed I will share the students results with them. I will also be happy to share the results with any parents who are interested.

If you have any questions regarding this study you may call me at 436-0987.

I encourage you to discuss this letter with your child and sign the attached form and return it to Mr. Bob Wightman at McCord Middle School by _____.

Students who elect not to participate in this project will not take the tests described in the third paragraph but will participate in the three days of science activities as they are part of the science curriculum.

I would like to thank you in advance for your cooperation. I think this study will be interesting and challenging for your eighth grader.

Abigail Harding

Abigail Harding

September 30, 1989

My child, _____

_____ has my permission to participate in the research project as described by Ms. Harding in the enclosed letter.

_____ does not have my permission to participate in the research project described by Ms. Harding in the enclosed letter.

_____

PARENT/GUARDIAN DATE

Please return this form to Mr. Wightman by _____.

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